Does variance risk have two prices?
Evidence from the equity and option markets✩

Laurent Barras*,a, Aytek Malkhozovb

*aMcGill University, Desautels Faculty of Management
Bronfman Building, 1001 Sherbrooke St West, H3A1G5 Montreal, Canada
bBank for International Settlements
Centralbahnplatz 2, 4051 Basel, Switzerland

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.

JEL classification: G12, G13, C58

Keywords: Variance risk premium, Option, Equity, Financial intermediaries

✩We would like to thank Torben Andersen, Turan Bali, David Bates, Geert Bekaert, Sebastien Betermier, Peter Christoffersen, Ben Cohen, Stefano Giglio, Ruslan Goyenko, Alan Moreira, Nicolas Mongeot, Philippe Mueller, Elisa Ossola, Lasse Pedersen, Christopher Polk, Sergei Sarkissian, Olivier Scaillet, Viktor Todorov, Fabio Trojani, Christian Upper, Andrea Vedolin, Hao Zhou and seminar participants at the Bank for International Settlements, the Bank of England, the Copenhagen Business School, the Federal Reserve Board, the London School of Economics Systemic Risk Centre, the University of Sherbrooke, the 2014 CIRPÉE (Centre interuniversitaire sur le risque, les politiques économiques et l’emploi) Applied Financial Time Series Conference, the 2014 Dauphine Amundi Chair in Asset Management Workshop, the 2014 Montreal Institute of Structured Finance and Derivatives (IFSID) Conference on Derivatives, the 2014 meeting of the Institute for Mathematical Finance, the 2014 National Bureau of Economic Research Summer Institute, the 2014 Paris Finance Conference, and the 2016 American Finance Association Annual Meeting. We are grateful to the editor Bill Schwert and an anonymous referee for numerous helpful insights. We also gratefully acknowledge financial support from IFSID. The views expressed in this paper are ours and do not necessarily reflect those of the Bank for International Settlements.

*Corresponding author. Tel.: +1 514-398-8862.
Email address: laurent.barras@mcgill.ca (Laurent Barras)
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). For this reason, academics and policy makers alike commonly view the option VRP as the most readily available gauge of investors’ risk aversion or, more colloquially, fear. 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. If option prices reflect local demand and supply forces in addition to broad economic fundamentals, the option VRP could behave 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 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 Volatility Index (VIX) which measures the price of an index option.

---

2 The mispricing of Standard and Poor’s 500 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 (2016), and Garleanu, Pedersen, and Poteshman (2009).
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, 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 2007-2008. 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). For instance, when these intermediaries take on leverage or make short-term gains, the magnitude of the option VRP decreases significantly, whereas the equity VRP remains unchanged. Equivalently, 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 a misspecification of the factor model used to extract the equity VRP. We perform a large battery of tests and find it is not the case. The pricing errors are small, the model-implied mimicking portfolio closely tracks the market variance, and the inclusion of additional risk factors leaves the results unchanged. Second, we rely on theoretical and simulation analysis to show that variance jumps are unlikely to drive our results. Finally, we find the same VRP difference when repeating the entire estimation using monthly data or individual stocks (instead of portfolios).

3See, for instance, Adrian and Shin (2010, 2014), 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.
The VRP 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, which is frequently interpreted as a measure of investors’ risk aversion and future economic activity. However, this interpretation could be misleading if the two broker-dealer variables that drive the option VRP mainly capture shocks that are specific to intermediaries. Consistent with this view, changes in both variables do not affect the risk attitude of equity investors toward stocks exposed to variance risk. In addition, 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 is that investors face portfolio constraints that induce market segmentation. In practice, such constraints can 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 stocks exposed to variance risk. An alternative explanation proposed by Garleanu and Pedersen (2011) is that investors with limited capital can value identical assets differently 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. It cannot easily explain that the VRP difference takes both positive and negative values because margins are unlikely to be higher in the option market than in the equity market. Furthermore, it predicts that the VRP difference should increase when investors’ capital, or funding liquidity, is low (and vice versa). However, measures of funding liquidity such as the default and TED spreads are weakly related to the VRP difference.

Finally, our results emphasize the key role played by financial intermediaries in the index option market. As shown empirically by Chen, Joslin, and Ni (2016) and Garleanu, Pedersen, and Poteshman (2009), broker-dealers supply index options to public investors in exchange for a premium for holding residual risk. Therefore, their ability to perform this task should depend on their ability to

---

4 Market segmentation is also commonly used to explain mispricing across international markets. See, e.g., Bekaert, Harvey, Lundblad, and Siegel (2011).
to bear risk and take on leverage. If leverage 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, which is not over-turned 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 relation between leverage and the option VRP extracted from index option prices.

Our work is related to several strands of the literature. First, an extensive literature exists 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, and Bansal, Kiku, Shaliastovich, and Yaron (2014) and Campbell, Giglio, Polk, and Turley (2015) derive an intertemporal CAPM with stochastic volatility to explain the cross section of average stock returns. Relative to these papers, we perform a conditional analysis of the equity VRP and study the drivers of its variation over time. 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 Standard and Poor’s (S&P) 500 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 (2016) 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; Section 4 the main empirical findings. Section 5 provides several interpretations for our main findings, and Section 6 concludes. The Online Appendix provides a detailed description of

Ang, Hodrick, Xing, and Zhang (2006) present independent evidence on the pricing of both market (systematic) and idiosyncratic variance risks. Our work focuses exclusively on their analysis of market variance risk.
the methodology and reports additional results.

2. Empirical framework

In this Section, we define the conditional market variance risk premium, and then present the methodology used to estimate this premium in the equity and option markets.

2.1. The market variance risk premium

We define the conditional VRP as

\[ \lambda_{v,t} = E(rv_{t+1}|I_t) - EQ(rv_{t+1}|I_t) = E(rv_{t+1}|I_t) - p_{rv,t}, \]  

where \( rv_{t+1} \) is the realized variance of the market returns between time \( t \) and \( t+1 \), \( E(rv_{t+1}|I_t) \) and \( EQ(rv_{t+1}|I_t) \) denote the physical and risk-neutral expectations of \( rv_{t+1} \) conditioned on all available information at time \( t \). The term \( EQ(rv_{t+1}|I_t) \) 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 Eq. (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., Bakshi and Kapadia, 2003; 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 conditional 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:

\[ \lambda_{v,t}(z) = proj(rv_{t+1}|z_t) - proj(p_{rv,t}|z_t) = F'_v z_t - V'_v z_t, \]  

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 market variance risk differ. Building on this insight, we compute the equity- and option-based estimates of $\lambda_{v,t}(z)$ as

$$
\hat{\lambda}_{v,t}^e(z) = (\hat{F}_v - \hat{V}_v^e)^\top z_t,
\hat{\lambda}_{v,t}^o(z) = (\hat{F}_v - \hat{V}_v^o)^\top z_t,
$$

(3)

where $\hat{V}_v^e z_t$ and $\hat{V}_v^o z_t$ 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:

$$
\hat{D}_t(z) = \hat{\lambda}_{v,t}^e(z) - \hat{\lambda}_{v,t}^o(z) = (\hat{V}_v^o - \hat{V}_v^e)^\top z_t.
$$

(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; that is, $\hat{D}_t(z)$ depends only on $\hat{V}_v^e$ and $\hat{V}_v^o$, 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 $r_{v,t+1}$ on $z_t$, similar to Campbell, Giglio, Polk, and Turley (2015) and Paye (2012). The two vectors of risk-neutral coefficients $\hat{V}_v^e$ and $\hat{V}_v^o$ are recovered from a set of equity and option portfolios that are exposed to the variance risk of the market. For sake of brevity, we describe the main steps of the procedure below and relegate to the Online Appendix additional details on the properties of the different estimators, which are all consistent and asymptotically normally distributed.

---

The opposite does not hold, i.e., the projections can be equal even if the VRPs differ. This situation arises when the difference between the two VRPs is orthogonal to the predictors.
2.2. The equity-based vector $V^e$ 

The theoretical and empirical evidence shows that the market variance $r_{vt+1}$ 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 that of Ang, Hodrick, Xing, and Zhang (2006) by sorting stocks monthly into quintiles based on their betas on the market and variance factors (see the Online Appendix for a detailed description). To estimate the equity-based vector $V^e$, we posit a parsimonious two-factor model for the excess return of each equity portfolio $p \ (p = 1, \ldots, 25)$:

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

where $f_{m,t+1}$ is the market excess return, $b_{pv}$ and $b_{pm}$ denote the portfolio betas, $\epsilon_{p,t+1}$ is the idiosyncratic component, and the equilibrium forward price $p_{p,t}$ is equal to $b_{pv} \cdot p^f_{rv,t} + b_{pm} \cdot p^f_{fm,t}$, where $p^f_{rv,t}$ and $p^f_{fm,t}$ are the forward prices of the two risk factors formed in the equity market.

Specifying a two-factor model with constant betas is motivated by the fact that the 25 portfolios are sorted along the market and variance dimensions and rebalanced monthly to maintain stable exposures to both factors.

If we project $r^e_{p,t+1}$ on the space spanned by $z_t$, $r_{vt+1}$, and $f_{m,t+1}$ and use the equilibrium price condition, we can write the excess portfolio return as

$$
 r^e_{p,t+1} = -c'_p z_t + b_{pv} \cdot r_{vt+1} + b_{pm} \cdot f_{m,t+1} + \epsilon_{p,t+1}
$$

and the projected forward price as

$$
 \text{proj}(p_{p,t} | z_t) = c'_p z_t = (b_{pv} \cdot V^e_{v,t} + b_{pm} \cdot V^e_{m,t}) z_t,
$$

where $V^e_{v,t}$ and $V^e_{m,t}$ denote the projections of $p^f_{rv,t}$ and $p^f_{fm,t}$ on $z_t$, respectively. Eqs. (6) and 7

---

7This last equality is perfectly equivalent to the more familiar equality that applies to conditional returns. To see this, we can replace $r_{vt+1}$ and $f_{m,t+1}$ with their demeaned versions, $\tilde{r}_{vt+1}$ and $\tilde{f}_{m,t+1}$, and use the fact that $\lambda^e_{v,t} = E(r_{vt+1} | I_t) - p^f_{rv,t}$ and $\lambda^e_{m,t} = E(f_{m,t+1} | I_t) - p^f_{fm,t}$ to rewrite Eq. 5 as $r^e_{p,t+1} = E(r^e_{p,t+1} | I_t) + b_{pv} \cdot \tilde{r}_{vt+1} + b_{pm} \cdot \tilde{f}_{m,t+1} + \epsilon_{p,t+1}$, where $E(r^e_{p,t+1} | I_t)$ must be equal to $b_{pv} \cdot \lambda^e_{v,t} + b_{pm} \cdot \lambda^e_{m,t}$ (see Cochrane, 2005). Because $f_{m,t+1}$ is an excess return, its forward price must be equal to zero ($p^f_{fm,t} = 0$). This condition provides us with a test of the validity of the model (see Subsection 4.4).
serve as the two building blocks for our estimation procedure, which is based on recent work by Gagliardini, Ossola, and Scaillet (2015) that extends the classic two-pass cross-sectional regression to the conditional setting considered here. In the first step, we run a time-series regression of \( r_{e_{p,t}} \) on \( z_t, r_{v,t+1} \), and \( f_{m,t+1} \) to estimate \( c_p, b_{pv}, \) and \( b_{pm} \) for each equity portfolio [(Eq. (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 \( V_{e_{v}} \) [Eq. (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 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. Extensive tests provide strong evidence that the two-factor model is correctly specified (see Subsection 4.4). Second, our approach should be distinguished from recent studies (e.g., Buraschi, Trojani, and Vedolin, 2014; Cao and Han, 2013) that 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 \( \hat{V}_{o} \)

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 \( r_{v,t+1} \) can be replicated by a portfolio of index options whose forward price is given by the squared VIX denoted \( \text{vix}_t^2 \). As a result, the forward price of \( r_{v,t+1} \) formed in the option market, denoted by \( p_{o_{v,t}} \), can be measured by \( \text{vix}_t^2 \). Exploiting this result, we compute \( \hat{V}_{o} \) from a simple time series regression of \( \text{vix}_t^2 \) on \( z_t \) as we have:

\[
\text{proj}(p_{o_{v,t}} | z_t) = \text{proj}(\text{vix}_t^2 | z_t) = V_{o_{v}} z_t.
\]  

\( \hat{V}_{e_{v}} \) and \( \hat{V}_{e_{m}} \) serve as the two building blocks for our estimation procedure, which is based on recent work by Gagliardini, Ossola, and Scaillet (2015) that extends the classic two-pass cross-sectional regression to the conditional setting considered here. In the first step, we run a time-series regression of \( r_{e_{p,t+1}} \) on \( z_t, r_{v,t+1} \), and \( f_{m,t+1} \) to estimate \( c_p, b_{pv}, \) and \( b_{pm} \) for each equity portfolio [(Eq. (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 \( V_{e_{v}} \) [Eq. (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 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. Extensive tests provide strong evidence that the two-factor model is correctly specified (see Subsection 4.4). Second, our approach should be distinguished from recent studies (e.g., Buraschi, Trojani, and Vedolin, 2014; Cao and Han, 2013) that 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 \( \hat{V}_{o} \)

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 \( r_{v,t+1} \) can be replicated by a portfolio of index options whose forward price is given by the squared VIX denoted \( \text{vix}_t^2 \). As a result, the forward price of \( r_{v,t+1} \) formed in the option market, denoted by \( p_{o_{v,t}} \), can be measured by \( \text{vix}_t^2 \). Exploiting this result, we compute \( \hat{V}_{o_{v}} \) from a simple time series regression of \( \text{vix}_t^2 \) on \( z_t \) as we have:

\[
\text{proj}(p_{o_{v,t}} | z_t) = \text{proj}(\text{vix}_t^2 | z_t) = V_{o_{v}} z_t.
\]
The only challenge when estimating $V_o$ 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 available only from 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 $V_o$ 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 $vix^2$, respectively (i.e., $z_t$ equals one). Now suppose that the estimated mean of $rv_{t+1}$ over the short sample, denoted $\hat{rv}_S$, is above the more precise estimate computed over the long sample. Because $rv_{t+1}$ and $vix_t^2$ are positively correlated, $\hat{vix}_S^2$ is also likely to be above average. Therefore, $\hat{vix}_S^2$ is adjusted downward to produce the final estimate.

3. Data description

In this Section, we describe the set of predictive variables, provide summary statistics for the 25 variance risk-sensitive equity portfolios, and examine the predictability of the market realized variance.

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-to-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 (2015), and Paye (2012). The Online Appendix provides more information on the definition of each predictor and displays some descriptive statistics.

In addition to the macro-finance variables, 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).\footnote{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.} Adrian and Shin (2010, 2014) 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. In bad times, they deleverage, possibly because of tighter Value-at-Risk constraints or higher risk aversion levels. Second, we borrow from Boyson, Stahel, and Stulz (2010) and compute the value-weighted index of publicly traded prime broker firms, including Goldman Sachs, Morgan Stanley, Bear Stearns, UBS, and Citigroup. The quarterly return of this prime broker index allows us to capture short-term changes in the financial strength of the major players in the brokerage sector.

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 Eq. (6), in which the market variance $r_{v,t+1}$ is proxied by the quarterly sum of the daily squared S&P 500 returns, the market $f_{m,t+1}$, by the quarterly excess return of the Center for Research in Security Prices (CRSP) index.

Consistent with theory, Table 1 shows a strong and negative beta-return relation (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 drops by 2.47% per year. Two additional results corroborate this negative beta-return relation. First, the Online Appendix presents similar findings over the short sample between 1992 and 2014 (the cross-correlation equals -0.92). Second, we find that, during the three largest variance shocks (Q4 1987, Q4 2008, Q3 2011), the market-hedged return of the high-minus low-variance portfolios is always positive (with an average return of 6.23% per quarter), and that the opposite pattern holds during the three lowest variance shocks (Q1 2012, Q2 2008, Q1 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.

The last four columns of Table 1 examine whether commonly used asset pricing models explain the average return difference across portfolios. Whereas positive variance shocks are associated 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. Finally, the models still fail to capture the cross section of average returns when we include traded momentum and Pastor-Stambaugh liquidity factors.

### 3.3. Market variance predictability

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

[Insert Table 2 near here]

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 relation between the default spread and the future realized variance. Because a risky bond is short the option to default, a low price signals that the future variance is expected to be above average. 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 shown by Campbell, Giglio, Polk, and Turley (2015) and Paye (2012) over the same quarterly frequency.

From previous work by Brunnermeier and Pedersen (2009), financial intermediation could amplify shocks to asset markets. Contrary to this view, Panel B reveals that the incremental ex-

\[^{12}\text{The Online Appendix reveals that the rejection of these models is stronger during the short sample.}\]
planatory power of the broker-dealer variables (leverage and PBI return) is weak in the presence of macro-finance predictors.

4. Main empirical results

We present our main results in four 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 strategy that trades variance risk. Fourth, we summarize the large battery of tests that verify the robustness of our empirical findings.

4.1. The determinants of the variance risk premia

In this Subsection, we separately examine the extent to which the macro-finance and broker-dealer variables affect the equity and option 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 $\hat{F}_v - \hat{V}_e^r$, where $\hat{F}_v$ is taken from Table 2 (Panel A) and the risk-neutral vector $V_e^r$ is estimated using the conditional two-pass regression described in Subsection 2.2. The results in Panel A of Table 3 (first row) reveal 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 ($-0.42 \cdot 4$). In volatile periods, assets that pay off when future volatility increases further become extremely valuable and this effect dominates the increase in expected future variance shown in Table 2 (i.e., $\hat{V}_e^rz_t > \hat{F}_v^rz_t$). Third, the physical and risk-neutral expectation effects offset each other for both the PE ratio and the default spread. 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 coefficient for the inflation rate is 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 $\hat{F}_v - \hat{V}_o$, where the risk-neutral vector $\hat{V}_o$ is obtained by regressing the squared VIX on the macro-finance variables using the GMM procedure described in Subsection 2.3. The VIX index is constructed from three-month S&P 500 option prices available over the short sample (1992–2014). Similar to the equity market, Panel A (second row) reveals that the average level of the option VRP is negative (~1.80% per year) and that the coefficients for realized variance and inflation are both statistically significant. The only notable difference comes from the PE ratio, with a coefficient that is significant only in the option market.

4.1.2. Adding the broker-dealer variables

Unlike the macro-finance variables, the broker-dealer variables have a different impact on the two markets. Panel B of Table 3 (first row) measures the incremental explanatory power of the two broker-dealer variables in the presence of the macro-finance variables. For the equity market, we find that their explanatory power is weak. The coefficients associated with the leverage ratio and 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 relations 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, but 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 relation between the PBI return and the option VRP and produces a positive and statistically significant coefficient (0.17).

---

13 The quarterly VIX is also referred to as the VXV and is computed using the same methodology as the 30-day VIX.
4.2. Comparing the equity and option markets

We formally compare the equity and option markets by focusing on the estimated vector $\hat{V}_o - \hat{V}_e$ 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 macrofinance 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 Fig. 1 the equity and option VRP projections measured as $(\hat{F}_o - \hat{V}_o)z_t$ and $(\hat{F}_e - \hat{V}_e)z_t$, respectively. The two premia are closely aligned, especially over the last decade. Both are characterized by transitory spikes that follow large volatility shocks (e.g., burst of the dot-com bubble, 2008 crisis), and drop during the two recessions recorded between 1992 and 2012. This strong similarity results in a correlation coefficient of 0.69 between the two projections. However, Fig. 1 also reveals important discrepancies between the two VRPs. The magnitude of the option VRP is substantially larger during the 2008 and European debt crises, and the opposite pattern is observed during the late 1990s and early 2000s. As illustrated in Fig. 2, these variations are closely associated with leverage. When intermediaries deleverage, we see that the price of variance risk is relatively higher in the option market (and vice versa).

4.3. Analysis over the short sample

In this Subsection, we focus on the short sample period to examine the stability of the VRP difference and the performance of a strategy that trades variance risk in both markets.
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 difference between the two markets is not an artifact 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 not their difference. For the broker-dealer variables, Panel B (third row) reveals that leverage remains strongly related to the VRP difference, and 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 that over the full sample.

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 $r_{e,t+1}$ 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 Online 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 Subsection 2.3, and its excess return $r_{o,t+1}$ is equal to $rv_{t+1} - vix_t^2$.

We examine the performance of a trading strategy that is long the variance-mimicking equity portfolio and 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:

$$r_{s,t+1} = r_{e,t+1} - r_{o,t+1} = a'_s z_t + b'_sf_{t+1} + e_{s,t+1},$$

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), and momentum- and liquidity-based extensions of FF]. Overall, the results mirror those found for the VRP difference in Tables 3 and 4 and confirm the key role played by the two broker-dealer variables. 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).

[Insert Table 5 near here]

4.4. Robustness analysis

To verify that the VRP difference is not driven by a misspecification of the two-factor model, we measure the magnitude of its pricing errors. Eq. (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 $Q = \sum_{p=1}^{25} \zeta_p^T \zeta_p$, where $\zeta_p = c_p - (b_{pv} \cdot V_v^e + b_{pm} \cdot V_m^e)$. Table 3 reveals that the test statistic ($J$-statistic) is far below the conventional rejection thresholds with or without the broker-dealer variables (the $p$-values range between 0.31 and 0.40).

In the Online Appendix, we also perform an extensive analysis to evaluate the robustness of our main results. First, we further verify that the two-factor model is correctly specified by examining the properties of the market risk premium, the hedging errors of the variance-mimicking portfolio, the impact of additional risk factors, and the degree of time variation in portfolio betas. Second, we demonstrate that variance jumps can affect the equity and option VRPs but can hardly explain their difference. Third, we find the same VRP difference when the estimation is based on monthly or individual stock data. In summary, the two broker-dealer variables reliably signal periods when the prices of variance risk differ across the two markets.

5. 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. Finally, we provide an economic interpretation for the strong relation between the broker-dealer variables and the option VRP.

---

14 The distribution of the test statistic is described in the Online Appendix.
5.1. Information content of the variance risk premia

The VRP inferred from option prices is commonly interpreted by academics and policy makers as a measure of investors’ risk aversion. Our empirical results reveal that this interpretation can be misleading because the information content of the option and equity VRPs is not always identical. Whereas both premia respond similarly to changes in economic and volatility conditions, the option VRP is disproportionately influenced by the broker-dealer variables. When financial intermediaries deleverage, the price of variance risk in the option market is high. Yet, this does not imply that equity investors change their attitude toward stocks exposed to variance risk.

The information contained in the VRP is also used to forecast broad economic indicators (e.g., Bekaert and Hoerova, 2014; Bollerslev, Tauchen, and Zhou, 2009). If the broker-dealer variables capture shocks that are specific to intermediaries, then we expect the option VRP projection to have a lower predictive ability than its equity-based counterpart. Consistent with this interpretation, we find that the ability of the broker-dealer variables to predict economic fundamentals is weak. Panel A of Table 6 reports the estimated coefficients of the predictive regressions of the future quarterly market return and industrial production growth on a set of predictors that include the macro-finance variables, the broker-dealer variables, and the non-projected option VRP commonly used in previous studies and defined as $\hat{F}_0^{\text{z}} - \text{vix}_t^2$. The results show that several macro-finance variables are strong predictors of the market return and economic activity. On the contrary, none of the estimated coefficients for the leverage and PBI return is statistically significant.

Panel B formally evaluates the predictive ability of the equity VRP projection, the option VRP projection, and the non-projected option VRP. In line with our previous findings (Panel A), the coefficients for the equity VRP projection are all statistically significant, and those for the option VRP projection are not. We also find that the non-projected option VRP helps forecast the market return, which resonates with the results presented by Bollerslev, Tauchen, and Zhou (2009).

15 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.
5.2. Possible explanations for the VRP difference

The rejection of the null hypothesis of equal VRPs means that the same variance risk is traded at different prices. This result can be explained by market frictions such as informational and regulatory constraints that limit risk sharing between marginal investors in the equity and option markets. Basak and Croitoru (2000) demonstrate theoretically that when investors face portfolio constraints, markets are segmented and deviations from the law of one price can exist in equilibrium. In practice, these constraints can take several forms. Retail investors could lack the expertise required to monitor option positions and mutual funds face limits on the amount of options held in their portfolios. On their side, index option trading desks generally trade exclusively in index futures to manage the delta of their option positions, but not in stocks exposed to market variance risk. When the magnitude of the option VRP is high, equity investors are therefore unable to write options in sufficient number, and broker-dealers fail to trade in variance risk-sensitive stocks (and vice versa).

Alternatively, the gap between the two markets could be driven by different margin requirements. The margin-based asset pricing theory of Garleanu and Pedersen (2011) predicts that investors are willing to pay a higher price to be long in assets that carry lower margins because they consume less capital. Because margins are lower in the option market, this argument implies a higher price of variance risk in the option market or, equivalently, a positive difference between the equity and option VRPs. In addition, this difference should increase when investors’ funding constraints are tight (i.e., when capital is scarce).

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 Fig. 1 because margins in the option market are unlikely to become greater than in the equity

---

16 While the effects of trading costs on asset prices depend on multiple factors (including their form and magnitude), they could also induce market segmentation. This could be the case if, for instance, fixed trading costs are sufficiently large to limit investors’ participation in the equity and option markets. In addition, transaction costs can prevent the VRP difference that arises in segmented markets to be eliminated by unconstrained arbitrageurs. For instance, Figlewski (1989) argues that trading costs prevent professional investors from perfectly hedging their option positions in the equity market.

17 Anecdotal evidence suggests that during the 2008 financial crisis very few equity investors wrote put options in spite of their high prices. One notable exception is Warren Buffett, whose short positions in equity put options reached a notional size of $40 billion in 2008 (Triana 2013). Buffett built this position because he secured a deal in which puts were not marked-to-market in case of adverse market movements. Therefore, he benefited from a special treatment that is not available to most investors.
market. Second, under the margin-based story, the explanatory power of the broker-dealer variables stems from their ability to track changes in investors’ funding constraints. However, we find that alternative and arguably more direct measures of funding constraints, such as the default and TED spreads, do not produce a higher VRP difference, i.e., their coefficients either are not significant (default) or have the wrong sign (TED).

5.3. 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 (2016) and Garleanu, Pedersen, and Potoshman (2009) empirically demonstrate that public investors have a long net position in S&P 500 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 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 examine the relation 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, 2014), both variables should have a negative impact on option prices. In Table 7, we report the estimated vector \( \hat{V}_o \) from the regression of the squared VIX on the predictors. Because the VIX is a measure of option expensiveness, \( \hat{V}_o \) 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).

Two potential concerns arise with this supply-based interpretation. First, the leverage ratio could be an endogenous variable if it also measures the quantity of options traded in the market. In an endogenous regression of price on quantity, Hamilton (1994) demonstrates that the slope coefficient is negative when supply shocks are the main determinants of the traded price and quantity. Therefore, the empirical evidence remains consistent with a supply-based mechanism. Second, the results could be affected by the omission of a relevant variable. While this case cannot be definitively ruled out, our baseline specification includes several macro-finance variables that potentially
drive option prices. We also examine several additional predictors that all leave the explanatory power of the broker-dealer variables unchanged (see the Online Appendix).\(^{18}\)

To shed further light on the supply-based mechanism, we repeat our analysis on the price of individual stock variance risk (changes in individual stock variances) and the price of correlation risk (changes in the correlation structure of stocks).\(^{19}\) Whereas the VIX is inferred from index options, the price of individual stock variance risk is computed from individual stock options whose supply is not dominated by financial intermediaries (see Garleanu, Pedersen, and Poteshman, 2009). Therefore, changes in their risk-bearing capacity are less likely to drive the prices of these options. Consistent with this interpretation, the results reported in the Online Appendix reveal that the relation between leverage and the price of stock variance risk is positive and not statistically significant. For the price of correlation risk, we find similar results to those in Table 7 for the VIX. This similarity resonates with the study by Driessen, Maenhout, and Vilkov (2009) which finds that the market VRP is mostly attributed to the premium for bearing correlation risk.

6. Conclusion

In this paper, we formally compare two conditional 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 each other 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. An increase in the leverage or past performance of intermediaries decreases the magnitude of the option VRP (or vice versa) 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 relation between the broker-dealer variables and the option VRP are consistent with the key role played by financial intermediaries in the option market.

\(^{18}\)Cheng, Kirilenko, and Xiong (2015) and Etula (2013) also provide empirical evidence that the risk-bearing capacity of intermediaries negatively affect 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.

\(^{19}\)We thank the referee for suggesting this analysis. We also thank Fabio Trojani, Andrea Vedolin, and Gregory Vilkov for sharing their data described in the Online Appendix.
These results can be exploited in future theoretical work that attempts to explain the aggregate pricing of variance risk and to 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 policy makers (e.g., Bernanke and Kuttner 2005, Rajan 2006) and an interesting avenue of future research.
References


23


Table 1
Summary statistics for the variance portfolios

This table shows the annualized excess mean, volatility, size (in log form), book-to-market (BM) ratio, and the pre- and 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). The last four columns report the 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 (FF+M) and liquidity (FF+L) factors, respectively. Means, volatilities, and alphas are in percent per year. The figures in parentheses report the heteroskedasticity-robust t-statistics. ***, **, and * designate statistical significance at the 1%, 5%, and 10% level, respectively.

<table>
<thead>
<tr>
<th>Quintile</th>
<th>Mean</th>
<th>Volatility</th>
<th>Size</th>
<th>BM</th>
<th>Pre-rank</th>
<th>Post-rank</th>
<th>CAPM</th>
<th>FF</th>
<th>FF+M</th>
<th>FF+L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>7.78</td>
<td>16.99</td>
<td>8.14</td>
<td>0.73</td>
<td>−0.70**</td>
<td>−0.68***</td>
<td>1.75**</td>
<td>0.29</td>
<td>0.23</td>
<td>−0.04</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(−2.24)</td>
<td>(−3.16)</td>
<td>(1.97)</td>
<td>(0.32)</td>
<td>(0.28)</td>
<td>(−0.05)</td>
</tr>
<tr>
<td>2</td>
<td>7.55</td>
<td>17.27</td>
<td>8.24</td>
<td>0.72</td>
<td>−0.32</td>
<td>−0.56***</td>
<td>1.44</td>
<td>0.20</td>
<td>−0.12</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(−0.84)</td>
<td>(−3.06)</td>
<td>(1.47)</td>
<td>(0.24)</td>
<td>(−0.11)</td>
<td>(0.24)</td>
</tr>
<tr>
<td>3</td>
<td>6.57</td>
<td>16.54</td>
<td>8.30</td>
<td>0.71</td>
<td>−0.03</td>
<td>−0.47**</td>
<td>0.58</td>
<td>−0.65</td>
<td>−0.11</td>
<td>−0.70</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(−0.09)</td>
<td>(−2.53)</td>
<td>(0.79)</td>
<td>(−0.95)</td>
<td>(−0.16)</td>
<td>(−1.07)</td>
</tr>
<tr>
<td>4</td>
<td>5.42</td>
<td>17.05</td>
<td>8.29</td>
<td>0.71</td>
<td>0.26</td>
<td>−0.22</td>
<td>−0.75</td>
<td>−1.85***</td>
<td>−2.27***</td>
<td>−1.99***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.67)</td>
<td>(−1.48)</td>
<td>(−1.03)</td>
<td>(−2.85)</td>
<td>(−3.55)</td>
<td>(−2.91)</td>
</tr>
<tr>
<td>High</td>
<td>5.31</td>
<td>17.55</td>
<td>8.31</td>
<td>0.71</td>
<td>0.66**</td>
<td>0.10</td>
<td>−0.96</td>
<td>−2.12**</td>
<td>−1.74*</td>
<td>−2.22**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(2.12)</td>
<td>(0.44)</td>
<td>(−1.06)</td>
<td>(−2.56)</td>
<td>(−1.80)</td>
<td>(−2.53)</td>
</tr>
<tr>
<td>High-low</td>
<td>−2.47</td>
<td>7.02</td>
<td>0.17</td>
<td>−0.02</td>
<td>1.36***</td>
<td>0.78***</td>
<td>−2.71**</td>
<td>−2.41**</td>
<td>−2.00*</td>
<td>−2.18*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(4.37)</td>
<td>(3.53)</td>
<td>(−2.40)</td>
<td>(−2.00)</td>
<td>(−1.67)</td>
<td>(−1.85)</td>
</tr>
</tbody>
</table>
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 a set of macro-finance variables: the lagged realized variance (RV), the price-to-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 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% level, respectively.

Panel A: Macro-finance variables

<table>
<thead>
<tr>
<th>Mean</th>
<th>RV</th>
<th>PE</th>
<th>DEF</th>
<th>PPI</th>
<th>EMP</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Realized variance</td>
<td>0.73***</td>
<td>0.39***</td>
<td>0.26***</td>
<td>0.25**</td>
<td>0.12</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>(9.13)</td>
<td>(3.77)</td>
<td>(2.67)</td>
<td>(2.31)</td>
<td>(1.27)</td>
<td>(0.38)</td>
</tr>
</tbody>
</table>

Panel B: Contribution of broker-dealer variables

<table>
<thead>
<tr>
<th>Leverage</th>
<th>Prime broker index</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEV</td>
<td>$R^2$</td>
<td>PBI $R^2$</td>
</tr>
<tr>
<td>Realized variance</td>
<td>0.23</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>(0.97)</td>
<td>(-1.12)</td>
</tr>
</tbody>
</table>
Table 3
Equity and option variance risk premia

Panel A examines the relation between the macro-finance variables and the equity variance risk premium (VRP), the option VRP, and their difference. The variables are the lagged realized variance (RV), the price-to-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 and the generalized method of moments 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 Online Appendix.

***, **, and * designate statistical significance at the 1%, 5%, and 10% level, respectively.

Panel A: Macro-finance variables

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>RV</th>
<th>PE</th>
<th>DEF</th>
<th>PPI</th>
<th>EMP</th>
<th>J-statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equity VRP</td>
<td>$-0.42^{**}$</td>
<td>$-0.42^{*}$</td>
<td>0.24</td>
<td>0.17</td>
<td>0.48*</td>
<td>$-0.02$</td>
<td>4.55</td>
</tr>
<tr>
<td></td>
<td>(-1.96)</td>
<td>(-1.65)</td>
<td>(0.65)</td>
<td>(0.47)</td>
<td>(1.75)</td>
<td>(-0.07)</td>
<td>[0.40]</td>
</tr>
<tr>
<td>Option VRP</td>
<td>$-0.45^{***}$</td>
<td>$-0.34^{***}$</td>
<td>0.35***</td>
<td>0.01</td>
<td>0.19**</td>
<td>$-0.07$</td>
<td>(-0.72)</td>
</tr>
<tr>
<td></td>
<td>(-8.01)</td>
<td>(-3.70)</td>
<td>(3.42)</td>
<td>(0.12)</td>
<td>(2.22)</td>
<td>(-0.07)</td>
<td>(-0.72)</td>
</tr>
<tr>
<td>Difference</td>
<td>0.03</td>
<td>-0.09</td>
<td>-0.12</td>
<td>0.16</td>
<td>0.29</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.10)</td>
<td>(-0.39)</td>
<td>(-0.59)</td>
<td>(0.55)</td>
<td>(1.44)</td>
<td>(0.25)</td>
<td></td>
</tr>
</tbody>
</table>

Panel B: Contribution of broker-dealer variables

<table>
<thead>
<tr>
<th></th>
<th>Leverage</th>
<th></th>
<th>Prime broker index</th>
<th></th>
<th>Combined</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LEV</td>
<td>$J$-statistic</td>
<td>PBI</td>
<td>$J$-statistic</td>
<td>LEV</td>
<td>PBI</td>
</tr>
<tr>
<td>Equity VRP</td>
<td>-0.13</td>
<td>5.60</td>
<td>-0.10</td>
<td>5.34</td>
<td>-0.15</td>
<td>-0.11</td>
</tr>
<tr>
<td></td>
<td>(-0.52)</td>
<td>[0.31]</td>
<td>(-0.47)</td>
<td>[0.40]</td>
<td>(-0.59)</td>
<td>(-0.58)</td>
</tr>
<tr>
<td>Option VRP</td>
<td>0.31***</td>
<td>0.07</td>
<td>0.37***</td>
<td>0.17**</td>
<td>0.31***</td>
<td>0.17**</td>
</tr>
<tr>
<td></td>
<td>(3.84)</td>
<td>(0.83)</td>
<td>(4.68)</td>
<td>(2.03)</td>
<td>(3.84)</td>
<td>(0.83)</td>
</tr>
<tr>
<td>Difference</td>
<td>-0.43***</td>
<td>-0.17</td>
<td>-0.52***</td>
<td>-0.28**</td>
<td>-0.43***</td>
<td>-0.17</td>
</tr>
<tr>
<td></td>
<td>(-5.32)</td>
<td>(-1.40)</td>
<td>(-5.90)</td>
<td>(-2.31)</td>
<td>(-5.32)</td>
<td>(-1.40)</td>
</tr>
</tbody>
</table>
Table 4
Equity and option variance risk premia: short sample

Panel A examines the relation between the macro-finance variables and the equity variance risk premium (VRP), the option VRP, and their difference. The variables are the lagged realized variance (RV), the price-to-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-based coefficients are obtained from the conditional two-pass regression. 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 Online Appendix. $***$, $**$, and * designate statistical significance at the 1%, 5%, and 10% levels, respectively.

Panel A: Macro-finance variables

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>RV</th>
<th>PE</th>
<th>DEF</th>
<th>PPI</th>
<th>EMP</th>
<th>$J$-statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equity VRP</td>
<td>-0.64***</td>
<td>-0.16</td>
<td>0.23</td>
<td>0.42</td>
<td>0.68***</td>
<td>0.17</td>
<td>5.34</td>
</tr>
<tr>
<td></td>
<td>(-3.01)</td>
<td>(-0.54)</td>
<td>(0.66)</td>
<td>(1.06)</td>
<td>(2.96)</td>
<td>(0.51)</td>
<td>[0.18]</td>
</tr>
<tr>
<td>Option VRP</td>
<td>-0.32***</td>
<td>-0.25</td>
<td>0.19*</td>
<td>0.22</td>
<td>0.30***</td>
<td>-0.14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(-4.06)</td>
<td>(-1.55)</td>
<td>(1.85)</td>
<td>(0.97)</td>
<td>(2.65)</td>
<td>(-0.96)</td>
<td></td>
</tr>
<tr>
<td>Difference</td>
<td>-0.31</td>
<td>0.08</td>
<td>0.04</td>
<td>0.19</td>
<td>0.38</td>
<td>0.31</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(-0.95)</td>
<td>(0.13)</td>
<td>(0.29)</td>
<td>(0.72)</td>
<td>(1.20)</td>
<td>(1.16)</td>
<td></td>
</tr>
</tbody>
</table>

Panel B: Contribution of broker-dealer variables

<table>
<thead>
<tr>
<th></th>
<th>Leverage</th>
<th>Prime broker index</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LEV</td>
<td>PBI</td>
<td>LEV</td>
</tr>
<tr>
<td></td>
<td>$J$-statistic</td>
<td>$J$-statistic</td>
<td>$J$-statistic</td>
</tr>
<tr>
<td>Equity VRP</td>
<td>0.15</td>
<td>-0.22</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>(0.67)</td>
<td>(-1.06)</td>
<td>(0.53)</td>
</tr>
<tr>
<td>Option VRP</td>
<td>0.57***</td>
<td>0.09</td>
<td>0.64***</td>
</tr>
<tr>
<td></td>
<td>(4.23)</td>
<td>(0.78)</td>
<td>(4.50)</td>
</tr>
<tr>
<td>Difference</td>
<td>-0.41***</td>
<td>-0.31**</td>
<td>-0.51***</td>
</tr>
<tr>
<td></td>
<td>(-3.33)</td>
<td>(-2.06)</td>
<td>(-4.04)</td>
</tr>
</tbody>
</table>
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: the lagged realized variance (RV), the price-to-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 book-to-market 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% level, respectively.

| Mean RV PE DEF PPI EMP LEV PBI R² |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 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)         |                 |
| -0.00           | -0.04           | 0.21            | -0.18           | 0.04            | -0.31*          | -0.70***        | -0.28**         | 0.40            |
| (-0.01)         | (-0.20)         | (1.38)          | (-0.81)         | (0.41)          | (-1.68)         | (-5.70)         | (-2.54)         |                 |
| 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)         |                 |
| 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 (IP) growth on a set of predictors: the lagged realized variance (RV), the price-to-earnings ratio (PE), the default spread (DEF), the quarterly inflation rate (PPI), 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 $F_{t+1}^2 - \nu_t^2$. 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, the option VRP projection, and the 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% level, respectively.

### Panel A: Informational content of the predictors

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>RV</th>
<th>PE</th>
<th>DEF</th>
<th>PPI</th>
<th>EMP</th>
<th>LEV</th>
<th>PBI</th>
<th>Option VRP (non-projected)</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market</td>
<td>1.97***</td>
<td>2.49**</td>
<td>-3.39***</td>
<td>-3.29**</td>
<td>-1.64**</td>
<td>1.02</td>
<td>-0.74</td>
<td>0.55</td>
<td>-2.94***</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>(2.68)</td>
<td>(2.23)</td>
<td>(-3.15)</td>
<td>(-2.10)</td>
<td>(-2.02)</td>
<td>(0.80)</td>
<td>(-0.58)</td>
<td>(0.55)</td>
<td>(-3.44)</td>
<td></td>
</tr>
<tr>
<td>IP growth</td>
<td>0.59***</td>
<td>-0.24</td>
<td>-0.09</td>
<td>-0.72***</td>
<td>-0.10</td>
<td>0.03</td>
<td>-0.29</td>
<td>0.22</td>
<td>-0.10</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>(6.30)</td>
<td>(-1.53)</td>
<td>(-0.63)</td>
<td>(-3.45)</td>
<td>(-0.95)</td>
<td>(0.14)</td>
<td>(-1.61)</td>
<td>(1.53)</td>
<td>(-0.82)</td>
<td></td>
</tr>
</tbody>
</table>

### Panel B: Predictive power of the variance risk premia

<table>
<thead>
<tr>
<th></th>
<th>Equity VRP projection</th>
<th>Option VRP projection</th>
<th>Option VRP (non-projected)</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>VRP</td>
<td>$R^2$</td>
<td></td>
</tr>
<tr>
<td>Market</td>
<td>-1.34*</td>
<td>-3.22</td>
<td>-3.90***</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>(-1.67)</td>
<td>(-1.20)</td>
<td>(-2.88)</td>
<td></td>
</tr>
<tr>
<td>IP growth</td>
<td>0.39**</td>
<td>0.07</td>
<td>-0.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>(2.42)</td>
<td>(0.12)</td>
<td>(-0.00)</td>
<td></td>
</tr>
</tbody>
</table>
Table 7
The squared Volatility Index (VIX)

Panel A reports the estimated coefficients and the adjusted $R^2$ of the regression of the quarterly squared VIX on a set of macro-finance variables: the lagged realized variance (RV), the price-to-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 squared VIX and are computed using the generalized method of moments for samples of unequal lengths. 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% level, respectively.

### Panel A: Macro-finance variables

<table>
<thead>
<tr>
<th>Mean</th>
<th>RV</th>
<th>PE</th>
<th>DEF</th>
<th>PPI</th>
<th>EMP</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Squared</td>
<td>1.18***</td>
<td>0.73***</td>
<td>-0.09</td>
<td>0.24**</td>
<td>-0.07</td>
<td>0.09</td>
</tr>
<tr>
<td>VIX</td>
<td>(27.37)</td>
<td>(9.47)</td>
<td>(-0.97)</td>
<td>(3.46)</td>
<td>(-1.22)</td>
<td>(1.17)</td>
</tr>
</tbody>
</table>

### Panel B: Contribution of broker-dealer variables

<table>
<thead>
<tr>
<th>Leverage</th>
<th>Prime broker index</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEV</td>
<td>PBI</td>
<td>LEV</td>
</tr>
<tr>
<td>Squared</td>
<td>-0.07**</td>
<td>-0.14**</td>
</tr>
<tr>
<td>VIX</td>
<td>(-1.97)</td>
<td>(-2.07)</td>
</tr>
</tbody>
</table>
Fig. 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-to-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 reported only during the short sample (1992-2014) because the quarterly Volatility Index (VIX) is available only from 1992. The y-axis is in percent per quarter. Shaded areas correspond to National Bureau of Economic Research 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 Long Term Capital Management (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).
Fig. 2: Variance risk premium difference and broker-dealer leverage. This figure plots the quarterly difference between the equity and the option variance risk premia (solid line) obtained with the lagged realized variance, the price-to-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 quarter.