Online Appendix to Accompany “Downside Variance Risk Premium”

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Abstract

This Online Appendix contains additional empirical discussions supporting the decomposition of the variance risk premium into upside and downside components.

A Extracting Risk-neutral Quantities from Options

Since our study hinges on decomposition of the variance process into upside and downside semi-variances, we cannot follow BTZ by using VIX as a measure of risk-neutral volatility. As a result, we construct our own measures of risk-neutral upside and downside variances ($IV^{U/D}$). We use two sources of data to construct upside and downside IV measures. First, we obtain daily data of European-style put and call options on the S&P 500 index from OptionMetrics Ivy DB. We then match these options data with return series on the underlying S&P 500 index and risk-free rates downloaded from Center for Research in Security Prices (CRSP) files.

For each day in the sample period, beginning in September 1996 and ending in December 2010, we sort call and put options data by maturity and strike price. We construct option prices by averaging the bid and ask quotes for each contract. To obtain consistent risk-neutral moments, we preprocess the data by applying the same filters as in Chang, Christoffersen, and Jacobs (2013).[1] We only consider out-of-the-money (OTM) contracts. Such contracts are the most traded, and thus the most liquid, options. Thus, we discard call options with moneyness levels – the ratios of strike prices to the underlying asset price – lower than 97% ($\underline{S}/S < 0.97$). Similarly, we discard put options with moneyness levels greater than 103% ($\underline{S}/S > 1.03$). Raw option data contain discontinuous strike prices. Therefore, on each day and for any given maturity, we interpolate implied volatilities over a finely discretized moneyness domain ($\underline{S}/S$), using a cubic spline to obtain a dense set of implied volatilities. We restrict the interpolation procedure to days that have at least two OTM call prices and two OTM put prices available.

For out-of-range moneyness levels (below or above the observed moneyness levels in the market), we extrapolate the implied volatility of the lowest or highest available strike price. We perform this interpolation-extrapolation procedure to obtain a fine grid of 1,000 implied volatilities for moneyness levels between 0.01% and 300%. We then map these implied volatilities into call and put prices. Call prices are constructed for moneyness levels larger than 100% ($\underline{S}/S > 1$), whereas put prices are generated from moneyness levels smaller than 100% ($\underline{S}/S < 1$). We approximate the integrals using a recursive adaptive Lobatto quadrature. Finally, for any given future horizon of interest (1 to 24 months), we employ a linear interpolation to compute the corresponding moments. We obtain 3,860 daily observations of upside/downside risk-neutral variances for maturities from 1 to 24 months.

An important issue in the construction of risk-neutral measures is the respective density of put and call contracts, especially for deep OTM contracts. Explicitly, precise computation of risk-neutral volatility components hinges on comparable numbers of OTM put and call contracts in longer-horizon maturities (18 to 24 months). Our data set provides a rich environment that supports this data construction exercise. As is clear from Table A1, while there are more OTM put contracts than OTM call contracts by any of the three measures used – moneyness, maturity, or VIX level – the respective numbers of contracts are comparable. Figure A1 also shows that the growth of these contracts has continued unabated. We conclude that our construction of risk-neutral volatility components is not subject to bias because of the sparsity of data in deep OTM contracts. Moreover, a number of recent studies have raised concerns about the accuracy of traditional methods to evaluate risk-neutral expectations of realized higher moments. For instance, papers by Orlowski (2017) and Schneider and Trojani (2015) document that a non-trivial fraction of information is lost since the traditional approach uses a feasible incomplete-market replicating

[1] That is, we discard options with zero bids, those with average quotes less than \$3/8, and those whose quotes violate common no-arbitrage restrictions.

option portfolio (with a discrete set of options) to approximate a complete market form (which requires a compact set of options). This is due to the fact that a continuum of traded options in not available in the market. The feasible incomplete market approach in the traditional risk-neutral expectation assessment may imply a sizeable discretization error. Instead, the authors argue that $\mathbb{Q}$-expectations should be obtained from the prices of dynamically hedged trading strategies that exactly deliver the realized moment (typically, realized variance and its up/down components) as a payoff. This alternative technology dynamically optimizes the option portfolio weights by minimizing the discrepancy between the hedged quantity and the received payoff. Figure A2 shows that both approaches yield similar risk-neutral times series dynamics for one-month maturity. Indeed, the correlation between the risk neutral series from these two approaches is above 0.95.

Our computations are based on decompiling the variance risk premium based on realized returns to be above or below a cutoff point, $\kappa = 0$. However, κ is not directly applicable to the risk-neutral probability space. Thus, we make the appropriate transformation to use our cutoff point by letting r^f represent the instantaneous risk-free rate, and denote time to maturity by h. Then, for the market price index at time t, we define the applicable cutoff point as $b = F_t \exp(\kappa)$ using the forward price $F_t = S_t \exp\left(r^f h\right)$. We then use b to compute the risk-neutral upside and downside variances, which can thus be viewed as a model-free *corridor* of risk-neutral volatilities as discussed in Andersen, Bondarenko, and Gonzalez-Perez (2015), Andersen and Bondarenko (2007), and Carr and Madan (1999), among others.

B Additional Empirical Results

B.1 Out-of-sample analysis

Our goal in this section is to compare the forecast ability of downside variance and skewness risk premia with common financial and macroeconomic variables used in equity premium predictability exercises, beyond the in-sample fit.

To further assess the ability of downside variance risk and skewness risk premia to forecast excess returns, we follow the literature on predictive accuracy tests. We assume a benchmark model (referred to as B) and a competitor model (referred to as C) in order to compare their predictive power for a given sample $\{y\}_{t=1}^{T}$. To generate k-period out-of-sample predictions $y_{t+k|t}$ for y_{t+k}, we split the total sample of T observations into in-sample and out-of-sample portions, where the first $1, \ldots, t_R$ in-sample observations are used to obtain the initial set of regression estimates. The out-of-sample observations span the last portion of the total sample $t = t_R + 1, \ldots, T$ and are used for forecast evaluation. The models are recursively estimated with the last in-sample observation ranging from $t = t_R$ to $t = T - k$, at each t forecasting $t + k$. That is, we use time t data to forecast the k-step-ahead value. In our analysis, we use half of the total sample for the initial in-sample estimation, that is $t_R = \lfloor \frac{T}{2} \rfloor$, where $\lfloor \chi \rfloor$ denotes the largest integer that is less than or equal to χ. In order to generate subsequent sets of forecasts, we employ a recursive scheme (expanding window), even though the in-sample period can be fixed or rolling. The forecast errors from the two models are

$$
\begin{aligned}
e^{B}_{t+k|t} &= y_{t+k} - y^{B}_{t+k|t}, \\
e^{C}_{t+k|t} &= y_{t+k} - y^{C}_{t+k|t},
\end{aligned}
$$

where $t = t_R, \ldots, T - k$. Thus, we obtain two sets of $t = T - t_R - k + 1$ recursive forecast errors.

The accuracy of each forecast is measured by a loss function $L(\bullet)$. Among the popular loss functions are the squared error loss $L(e_{t+k|t}) = (e_{t+k|t})^2$ and the absolute error loss $L(e_{t+k|t}) =$

$|e_{t+k|t}|$. Let $d_t^{BC} = L(e_{t+k|t})^B - L(e_{t+k|t})^C$ be the error loss differential between the benchmark and competitor models, and denote the expectation operator by $\mathbb{E}(\bullet)$. To gauge whether a model yields better forecasts than an alternative specification, a two-sided test may be run, where the null hypothesis is that the "two models have the same forecast accuracy" against the alternative hypothesis that the "two models have different forecast accuracy." Formally:

$$H_0 : \mathbb{E}(d_t^{BC}) = 0 \text{ vs. } H_A : \mathbb{E}(d_t^{BC}) \neq 0.$$

Alternatively, a one-sided test may be considered, where the null hypothesis is that "model C does not improve the forecast accuracy compared to model B" against the alternative hypothesis that "model C improves the forecast accuracy compared to model B." Formally:

$$H_0 : \mathbb{E}(d_t^{BC}) \leq 0 \text{ vs. } H_A : \mathbb{E}(d_t^{BC}) > 0.$$

In the context of our study, we apply forecast accuracy tests to non-nested models. The innovation of our analysis is to introduce two new predictors, the VRP^D and SRP. We compare the benchmark model B, which includes our proposed predictors, and the competitor C, which contains a traditional predictive variable such as the price-dividend ratio, dividend yield, or price-earnings ratio. Failure to reject the null leads us to conclude that the classical predictor does not yield more accurate forecasts than our proposed predictor. Diebold and Mariano (1995) and West (1996) provide further inference results on this class of forecast accuracy tests.

Following the influential study of Inoue and Kilian (2004), we first investigate the in-sample fit of the data by our proposed predictors – the VRP^D and SRP – and traditional predictors studied in the literature. Inoue and Kilian (2004) convincingly argue that to make a dependable out-of-sample inference, we need reasonable in-sample fit. The second column of Table A2 reports adjusted R^2s for monthly, quarterly, and semi-annually aggregated excess returns regressed on our proposed and traditional predictors. These are in-sample results and no forecasting is performed. We notice that, first, for all predictors, adjusted R^2s improve with the prediction horizon. Second, we notice that for all predictors except Kelly and Pruitt's 2013 out-of-sample cross-sectional book-to-market index, adjusted R^2s are reasonably high. The Kelly-Pruitt index is by construction an out-of-sample predictor. Thus, the seemingly poor in-sample performance is not a cause for concern for us.

Once we establish the in-sample prediction power, we move to investigate out-of-sample forecast ability. Not surprisingly, out-of-sample adjusted R^2s – reported in the third column of Table A2 – are much smaller than their in-sample counterparts, with the exception of the Kelly-Pruitt index. This observation may be due to inclusion of data from the 2007 – 2009 Great Recession period in the out-of-sample exercise. Note that most predictors lose significant prediction power once data from this period is included in the analysis.

Our task is to investigate the relative forecast performance of our proposed downside and skewness risk premia measures against other well-known predictors. To this end, we implement the Diebold and Mariano (1995) (henceforth, DM) tests of prediction accuracy. The results of performing out-of-sample forecast accuracy tests are available in the fourth and sixth columns of Table A2, where we report DM test statistics, and in the fifth and seventh columns of the same table, where we report the associated p-values. We cannot reject the null of equal or superior forecast accuracy when the benchmark is the downside variance (or skewness) risk premium and the alternative model contains one of the traditional predictors, since p-values are greater than the conventional 5% test size. We note the following important considerations. First, these results are based on the DM forecast accuracy test for non-nested models. Our findings are robust for all the horizons we consider in our analysis (1, 3, and 6 months). Second, the null hypothesis states that the mean squared forecast error of the alternative model is larger than or equal to that of the benchmark model. This is a one-sided test, and negative DM statistics indicate that the alternative model performed worse than the benchmark model. Third, we interpret the p-values cautiously, following Boyer, Jacquier, and van Norden (2012). They point out that p-values are hard to interpret because of the Lindley-Smith paradox, and, in addition, they need to be adjusted. To be precise, we produce multiple p-values in this analysis. Using unadjusted p-values in such an environment overstates the evidence against the null. Thus, following Boyer, Jacquier, and van Norden (2012), we apply a Bonferroni adjustment to the generated p-values. Our reported findings are, therefore, suitably conservative and reliable. Conventional competing variables such as the variance risk premium, price-dividend ratio, and price-earnings ratio have lower forecast accuracy than our proposed measures.

In summary, the predictive power of the downside variance risk premium and skewness risk premium are not a figment of a good in-sample fit of the data. In comparison with other pricing ratios and variables, our proposed measures have at least similar (and often superior) out-of-sample accuracy.

B.2 Links to macroeconomic variables, financial indicators, and events

Following Ludvigson and Ng (2009), we survey the correlations of variance, upside variance, downside variance, and skewness risk premia with 125 financial and economic indicators listed in Table A3. We carry out this exercise to document the contemporaneous correlation of variance and skewness risk premia with well-known macroeconomic and financial variables. The VRP and its components are predictors of risk in financial markets; that is, an increase in VRP or VRP^D implies expectations of elevated risk levels in the future and, hence, compensation for bearing that risk. Fama and French (1989) document the counter-cyclical behavior of the equity premium: Investors demand a higher equity premium in bad times. It follows that VRP should be mildly pro-cyclical and positively correlated with cyclical macroeconomic and financial variables. The relationship between SRP and macroeconomic and financial factors is an empirically open issue that we address in this study. Finally, we are interested in the spanning of VRP, its components, and SRP by macroeconomic and financial factors. Briefly, low levels of spanning imply that the information content in the risk premium measures is nearly orthogonal to the information content of common financial or economic quantities.

The analysis and results here are based on a contemporaneous univariate regression, where the dependent variable is one of the variance or skewness risk premium measures, and the independent variable is one of the financial or economic variables.[2] Table A4 reports the 10 variables that yield the highest R^2s (wide-ranging above the 10% threshold) for each (semi-)variance risk premium component, and their respective slope parameter Student-t statistics that suggest significant relationships at conventional levels.

The estimated slope parameters for VRP and its components imply positive correlations with the mainly pro-cyclical macroeconomic variables listed in the table. Overall, payroll measures and industrial production indices exhibit strong contemporaneous links with VRP and its components. For instance, total payroll in the private sector yields an adjusted R^2 of over 50% for VRP^U, 40% for VRP, and about 25% for VRP^D.

[2]The complete list of these variables and supplementary results regarding our analysis are available in an online Appendix.

Slope parameters for the regression model containing SRP as the predicted variable and macroeconomic and financial variables as predictors imply a negative contemporaneous correlation. The sources of predictability for the SRP – while much weaker – are diverse. The top variables with significant correlation with SRP differ from those in the other three panels of Table A4. For example, total payroll in the private sector does not have much explanatory power for the SRP; it yields an adjusted R^2 equal to 11.63% and is the 9^{th} variable in the list. Since payroll measures are pro-cyclical, these findings imply counter-cyclical behavior for the SRP.

Together, these regularities lead us to conclude that the common financial and macroeconomic indicators do not fully span the VRP components or SRP, since none explain more than 53% of the variation in these premia contemporaneously. Moreover, these indicators seem to have the least success spanning downside variance and skewness risk premia. This observation sheds further light on the success of these two variables in predicting equity premia – they contain relevant information beyond that of a large set of common macroeconomic and financial variables.

B.3 News and Resolution of Uncertainty

To deepen our analysis, we follow Amengual and Xiu (2014) and investigate the impact of decisions and announcements that reduce or resolve uncertainty. We use the same set of events compiled by Amengual and Xiu (2014) to study the impact of important FOMC announcements, speeches by Federal Reserve officials and the Presidents of the United States, as well as economic and political news. The events are summarized in Table A5.

Table A6 gives the changes in variance, upside variance, downside variance, and skewness risk premia as well as their end-of-the-day levels on event dates. The most striking outcome from this exercise is the observation that across the board and for all variance risk components and skewness risk premia, policy announcements that resolve financial or monetary uncertainty also reduce the premia. The impact on the SRP, however, is mixed: Announcements can increase or decrease the size of this premium. This observation, by construction, hinges on the size of the reduction imputed by the announcement on VRP^U and VRP^D. That said, in 16 out of 22 events studied, the impact of events on the SRP is negative.

To track the major changes in (up/down) variance and skewness risk premia in the temporal neighborhood of an event, we perform targeted searches in suitably chosen date intervals – in this case, a trading week before and after the event date. Most large movements are very close to the event date, consistent with the results in Table A6. These observations suggest that resolution of policy uncertainty or reduction of political tensions has a negative impact on premia demanded by the market participants to bear variance or skewness risk.

Table A1: **S&P 500 Index Options Data**

	OTM Put			OTM Call			
Panel A: By Moneyness	$\underline{S}/S < 0.97$	$0.97 < \underline{S}/S < 0.99$	$0.99 < \underline{S}/S < 1.01$	$1.01 < \underline{S}/S < 1.03$	$1.03 < \underline{S}/S < 1.05$	$\underline{S}/S > 1.05$	All
Number of contracts	223,579	57,188	71,879	57,522	26,154	100,121	536,443
Average price	15.08	39.44	39.67	38.47	21.97	15.50	23.90
Average implied volatility	25.68	17.05	15.88	15.58	14.30	16.31	20.06

Panel B: By Maturity	DTM < 30	30 < DTM < 60	60 < DTM < 90	90 < DTM < 120	120 < DTM < 150	DTM > 150	All
Number of contracts	115,392	140,080	83,937	36,163	22,302	138,569	536,443
Average price	10.45	14.90	20.17	24.88	26.20	45.82	23.90
Average implied volatility	19.40	20.20	20.06	21.11	20.48	20.13	20.06

Panel C: By VIX Level	VIX < 15	15 < VIX < 20	20 < VIX < 25	25 < VIX < 30	30 < VIX < 35	VIX > 35	All
Number of contracts	74,048	115,970	164,832	88,146	37,008	56,439	536,443
Average price	17.90	20.70	24.89	26.84	26.80	28.93	23.90
Average implied volatility	11.63	15.92	19.42	22.20	25.31	34.72	20.06

This table sorts S&P 500 index options data by moneyness, maturity, and VIX level. Out-of-the-money (OTM) call and put options from OptionMetrics from September 3, 1996 to December 30, 2010 are used. The moneyness is measured by the ratio of the strike price ($\underline{S}$) to underlying asset price (S). DTM is the time to maturity in number of calendar days. The average price and the average implied volatility are expressed in dollars and percentages, respectively.

Table A2: **Out-of-Sample Analysis**

	$Adj.\ R^2(\%)\ for\ IS$	$Adj.\ R^2(\%)\ for\ OOS$	$dvrp\ vs.\ x_t$		$srp\ vs.\ x_t$	
			DM	$p-value$	DM	$p-value$
		Panel A: One Month				
$dvrp_t$	4.6723	0.6347			-0.0426	0.5170
srp_t	3.4862	-0.6055	0.0426	0.4830		
vrp_t	3.7175	-0.1087	-0.0271	0.5108	-0.0374	0.5149
$log(p_t/d_t)$	6.3871	-1.1465	-0.3716	0.6449	-0.4769	0.6833
$log(p_{t-1}/d_t)$	6.7059	-1.1123	-0.2414	0.5954	-0.3453	0.6351
$log(p_t/e_t)$	4.2430	-0.9384	0.2572	0.3985	0.2930	0.3848
$kpos_t$	-1.0697	2.0261	1.3282	0.0921	1.7998	0.0359
		Panel B: Three Months				
$dvrp_t$	24.6956	5.5674			0.0895	0.4644
srp_t	21.3847	-0.8775	-0.0895	0.5356		
vrp_t	19.8333	4.6494	0.3654	0.3574	0.2742	0.3919
$log(p_t/d_t)$	16.8502	-1.0456	0.5398	0.2947	0.6162	0.2689
$log(p_{t-1}/d_t)$	18.4235	-0.5345	0.5425	0.2937	0.6304	0.2642
$log(p_t/e_t)$	11.2493	0.2510	0.9778	0.1641	1.0725	0.1417
$kpos_t$	-0.6580	0.6473	1.7537	0.0397	1.8782	0.0302
		Panel C: Six Months				
$dvrp_t$	35.4498	0.1580			-1.2144	0.8877
srp_t	20.0010	2.3028	1.2144	0.1123		
vrp_t	31.7578	2.7778	-0.4553	0.6756	-1.0558	0.8545
$log(p_t/d_t)$	28.2580	0.4752	0.3393	0.3672	-1.2086	0.8866
$log(p_{t-1}/d_t)$	32.1452	1.2361	0.2877	0.3868	-1.2333	0.8913
$log(p_t/e_t)$	17.2860	1.0359	0.8114	0.2086	-0.6382	0.7383
$kpos_t$	2.9373	12.1162	1.7801	0.0375	1.2382	0.1078

This table presents the out-of-sample performance of predictors to forecast monthly ($r^e_{t\to t+1}$ in the top panel), quarterly ($r^e_{t\to t+3}/3$ in the middle panel) and semi-annually ($r^e_{t\to t+6}/6$ in the bottom panel) scaled cumulative excess returns, with observations spanning September 1996 to December 2010. The first two columns present the adjusted R^2 (%) for the in-sample (IS) and out-of-sample (OOS) observations – that is, the first and last half fractions of the data. The columns headed "$dvrp\ vs.\ x_t$" test the null hypothesis that "an alternative predictor (x_t) does not yield a better forecast than the downside variance risk premium ($dvrp$)." The columns headed "$srp\ vs.\ x_t$" test the null hypothesis that "an alternative predictor (x_t) does not yield a better forecast than the skewness risk premium (srp)." The reported test statistics and p-values are computed from the Diebold and Mariano (1995) model comparison procedure. Note that the Bonferroni adjustment is required when multiple p-values are produced, to avoid overstating the evidence against the null. Thus, to maintain an overall significance level of 5% (resp. 10%), one should adjust each individual test size to 0.0083 = 5%/6 (resp. 0.0167 = 10%/6) since 6 tests are performed for a given horizon.

Table A3: **Macroeconomic and Financial Time Series**

No	Series Name	No	Series Name
1	'Industrial Production Index, Total Index'	76	'USD Effective Exchange Rate Index
2	'IPI, Final Products and Nonindustrial Supplies (Total Products)'	77	'ISM Prices Index (Manufacturing)'
3	'IPI, Consumer Goods'	78	'PPI, Crude Petroleum (Domestic Production)'
4	'IPI, Durable Consumer Goods'	79	'PPI, Crude Materials'
5	'IPI, Nondurable Consumer Goods'	80	'PPI, Finished Consumer Goods'
6	'IPI, Automotive Products'	81	'PPI, Finished Goods'
7	'IPI, Business Equipment'	82	'PPI, Intermediate Materials, Supplies & Components'
8	'IPI, Defense & Space Equipment'	83	'CPI, All Items'
9	'IPI, Final Products'	84	'CPI, Services'
10	'IPI, Materials'	85	'CPI, All Items Less Food'
11	'IPI, Durable Goods Materials'	86	'CPI, All Items Less Shelter'
12	'IPI, Nondurable Goods Materials'	87	'CPI, All Items Less Medical Care'
13	'IPI, Energy (special aggregate)'	88	'CPI, All Items Less Food & Energy'
14	'IPI, Energy Materials (market group)'	89	'CPI, Commodities'
15	'IPI, Primary Energy (market group)'	90	'CPI, Durables'
16	'IPI, Converted Fuel (market group)'	91	'CPI, Apparel'
17	'IPI, Fuels (market group, within consumer energy products)'	92	'CPI, Transportaiton'
18	'IPI, Manufacturing (SIC)'	93	'CPI, Medical Care'
19	'ISM Production Index '	94	'Dow Jones Industrial Average'
20	'ISM Purchasing Mangers" Index (Manufacturing)'	95	'S&P 500 Dividend Yield'
21	'Capacity Utilization, Manufacturing (SIC)'	96	'S&P 500 Index'
22	'Personal Income'	97	'S&P 500 Industrials Index '
23	'Disposable Personal Income'	98	'S&P 500 PE'
24	'Personal Income Less Transfer Payments'	99	'M1 Index'
25	'Personal Saving'	100	'M2 Index'
26	'Personal Saving as % of Disposable Income'	101	'Consumer Credit Outstanding (nonrevolving)'
27	'Total Civilian Employment'	102	'Conference Board Consumer Confidence Index'
28	'Total Civilian Nonagricultural Employment'	103	'University of Michigan Consumer Sentiment Index'
29	'Total Civilian Unemployment'	104	'3-Month T-Bill'
30	'Unemployment Rate'	105	'6-Month T-Bill'
31	'Unemployment Rate, 16-19 yrs'	106	'1-Year Treasury'
32	'Avg. Weeks Unemployed'	107	5-Year Treasury
33	No Unemployed ¡ 5 weeks	108	3-Year Treasury
34	No Unemployed 5-14 weeks	109	10-Year Treasury
35	No Unemployed 15-26 weeks	110	20-Year Treasury
36	No Unemployed 15+ weeks	111	'Prime Rate'
37	No Unemployed 27+ weeks	112	'Moody"s AAA Corp. Index'
38	'ISM Employment Index (Manufacturing)'	113	'Moody"s AAA Muni. 10y Index'
39	'Nonfarm Payrolls, Total Private'	114	'Moody"s A Corporate Index'
40	'Nonfarm Payrolls, Goods-Producing'	115	'Moody"s Average Corporate Index'
41	'Nonfarm Payrolls, Mining and Logging (Natural Resources)'	116	'Moody"s BAA Corp. Index'
42	'Nonfarm Payrolls, Construction'	117	'3M-Fed Funds Spread'
43	'Nonfarm Payrolls, Manufacturing'	118	'6M-Fed Funds Spread'
44	'Nonfarm Payrolls, Durable Goods'	119	'1y-Fed Funds Spread'
45	'Nonfarm Payrolls, Nondurable Goods'	120	'5y-Fed Funds Spread'
46	'Nonfarm Payrolls, Services'	121	'10y-Fed Funds Spread'
47	'Nonfarm Payrolls, Transportation, Trade & Utilities'	122	'AAA Corp. - Fed Funds Spread'
48	'Nonfarm Payrolls, Wholesale Trade'	123	'BAA Corp. - Fed Funds Spread'
49	'Nonfarm Payrolls, Retail Trade'	124	'Effective Federal Funds Rate'
50	'Nonfarm Payrolls, Financial Sector'	125	'BAA Corp. - 10y Treasury Spread'
51	'Nonfarm Payrolls, Government'		
52	'Avg. Week Hrs Production/Non-Supervisory Empl, Goods-Producing'		
53	Avg. Week Hrs Production/Non-Supervisory Empl, Const		
54	Avg. Week Hrs Production/Non-Supervisory Empl, Manuf		
55	Avg. Week OT Hrs Production/Non-Supervisory Empl, Manuf'		
56	'Avg. Week Hrs Production/Non-Supervisory Empl, Durable Goods'		
57	'Avg. Hourly Earnings Production/Non-Supervisory Empl, Goods-Producing'		
58	'Avg. Hour Earnings, Production/Non-Supervisory Empl, Construction'		
59	Avg. Hour Earnings Production/Non-Supervisory Empl, Manuf		
60	'Personal Consumption Expenditures'		
61	'Durable Goods'		
62	'Nondurable Goods'		
63	'Services'		
64	'Manufacturers" New Orders- Consumer Goods & Materials '		
65	'New Orders- Nondefense Capital Goods'		
66	'ISM Supplier Deliveries Index (Manufacturing)'		
67	'ISM New Orders Index (Manufacturing)'		
68	'ISM Inventories Index (Manufacturing)'		
69	'Total New Private Housing Starts'		
70	'Midwest Housing Starts'		
71	'Northeast Housing Starts'		
72	'South Housing Starts'		
73	'West Housing Starts'		
74	'USDCAD'		
75	'GBPUSD'		

This table displays the names and the number associated with 125 macroeconomic and financial time series used in the analysis of relationship between variance and skewness risk premia and macroeconomic factors.

Table A4: **Relationship between Variance Risk Premium Components and Financial and Macroeconomic Variables**

Variance Risk Premium			Downside Variance Risk Premium		
Variable	t-Stat	R^2	Variable	t-Stat	R^2
Nonfarm Payrolls, Total Private	11.44	41.94	Nonfarm Payrolls, Total Private	7.67	24.52
Nonfarm Payrolls, Wholesale Trade	10.55	38.06	IPI, Durable Goods Materials	7.08	21.70
IPI, Durable Goods Materials	9.61	33.79	Nonfarm Payrolls, Wholesale Trade	6.99	21.26
Nonfarm Payrolls, Transportation, Trade & Utilities	9.16	31.69	Industrial Production Index, Total Index	6.81	20.40
Nonfarm Payrolls, Services	8.90	30.46	IPI, Final Products and Nonindustrial Supplies	6.62	19.47
IPI, Manufacturing (SIC)	8.27	27.45	IPI, Manufacturing (SIC)	6.57	19.25
IPI, Final Products and Nonindustrial Supplies	8.20	27.08	Nonfarm Payrolls, Transportation, Trade & Utilities	6.39	18.41
Nonfarm Payrolls, Retail Trade	8.16	26.89	Nonfarm Payrolls, Services	6.25	17.77
Industrial Production Index, Total Index	7.96	25.92	Nonfarm Payrolls, Retail Trade	5.84	15.84
Nonfarm Payrolls, Construction	7.80	25.15	IPI, Final Products	5.73	15.37
Upside Variance Risk Premium			Skewness Risk Premium		
Variable	t-Stat	R^2	Variable	t-Stat	R^2
Nonfarm Payrolls, Total Private	14.24	52.82	PPI, Intermediate Materials, Supplies & Components	-5.92	16.23
Nonfarm Payrolls, Wholesale Trade	13.41	49.85	Nonfarm Payrolls, Mining and Logging	-5.67	15.09
Nonfarm Payrolls, Transportation, Trade & Utilities	10.94	39.82	Nonfarm Payrolls, Construction	-5.26	13.24
IPI, Durable Goods Materials	10.67	38.61	Nonfarm Payrolls, Wholesale Trade	-5.11	12.61
Nonfarm Payrolls, Services	10.66	38.56	1-Year Treasury	-5.06	12.39
Nonfarm Payrolls, Construction	10.38	37.31	CPI, All Items	-4.98	12.03
Nonfarm Payrolls, Retail Trade	9.51	33.33	CPI, All Items Less Medical Care	-4.95	11.94
IPI, Manufacturing (SIC)	8.49	28.50	6-Month Treasury Bill	-4.92	11.80
IPI, Final Products and Nonindustrial Supplies	8.31	27.63	Nonfarm Payrolls, Total Private	-4.88	11.63
Nonfarm Payrolls, Financial Sector	8.01	26.18	CPI, All Items Less Food	-4.82	11.36

This table reports the 10 macroeconomic variables that demonstrate high contemporaneous correlation and explanatory power for variance and skewness risk premia. The results are sorted based on the size of adjusted R^2s from performing a univariate, linear regression analysis where the dependent variable is either the variance risk premium, upside variance risk premium, downside variance risk premium, or skewness risk premium, and the independent variable is one of the 124 macroeconomic and financial variable series studied by Feunou et al. (2014). Both adjusted R^2s and Student's t-statistics for the slope parameters are reported.

Table A5: **Policy News Potentially Associated with Volatility Changes–Both Dates**

Date	ΔVariance	ΔReturn	News
08/18/98	-0.373 (-0.365)	0.013	President Clinton admits to "wrong" relationship with Ms. Lewinsky and FOMC's decision to leave interest rates unchanged
09/01/98	-0.722 (-0.664)	0.035	Fed adds money to the banking system with Repo
09/08/98	-0.526 (-0.455)	0.021	Fed Chairman Greenspan's statement that a rate cut might be forthcoming
09/14/98	-0.185		President Clinton advocated a coordinated global policy for economic growth in NYC
09/23/98	-0.344 (-0.280)	0.027	Fed Chairman Greenspan testimony before the Committee on the Budget, U.S. Senate
10/20/98	-0.253	-0.007	3 big US banks delivered better-than-expected earnings and bullish mood after Fed rate cut previous week
08/11/99	-0.266 (-0.276)	0.008	Fed Beige Book release shows that US economic growth remains strong
01/07/00	-0.500	0.031	Unemployment report shows the lowest unemployment rate in the past 30 years
03/16/00	-0.266	0.037	Release of Inflation Remains Tame Enough to Keep the Federal Reserve from tightening credit
04/17/00	-0.373 (-0.296)	0.032	Treasury Secretary Lawrence H. Summers Statement that fundamentals of the economy are in place
10/19/00	-0.241	0.018	Feds Greenspan Gives Keynote Speech at Cato Institute and jobless claims drop by 7,000 in the latest week
01/03/01	-0.282 (-0.179)	0.052	Fed's Announcement of a Surprise, Inter-Meeting Rate Cut
05/17/05	-0.275 (-0.303)	0.01	John Snow calls on China to take an intermediate step in revaluing its currency
05/19/05	-0.297		Fed Chairman A. Greenspan Steps up Criticism of Fannie Mae and Freddie Mac
06/15/06	-0.549 (-0.625)	0.017	Fed Chairman B. Bernanke's speech on inflation expectations within historical ranges
06/29/06	-0.295 (-0.325)	0.016	FOMC Statement to raise its target for the Federal Funds Rate by 25 bps
07/19/06	-0.272		Fed Chairman B. Bernanke warned that the Fed must guard against rising prices taking hold
02/28/07	-0.396		Fed Chairman B. Bernanke told a house panel that markets seem to be working well
03/06/07	-0.217		Henry Paulson in Tokyo said the global economy was as strong as he has ever seen
06/27/07	-0.271		FOMC announcement generated market rebound the previous date
08/21/07	-0.188		Senator Dodd said the Fed to deal with the turmoil after meeting with Paulson and Bernanke
09/18/07	-0.415 (-0.353)	0.024	FOMC decided to lower its target for the Federal Funds Rate by 50 bps
03/18/08	-0.216		Fed cuts the Federal Funds Rate by three-quarters of a percentage point
10/14/08	-0.489 (-0.304)	-0.048	FOMC decided to lower its target for the Federal Funds Rate by 50 bps
10/20/08	-0.426 (-0.413)	0.033	Fed Chairman B. Bernanke Testimony on the Budget, U.S. House of Representatives
10/28/08	-0.313 (-0.230)	0.075	Fed to Cut the Rate Following the Two-Day FOMC Meeting is Expected by the Market
11/13/08	-0.328 (-0.240)	0.062	President Bush's Speech on Financial Crisis
12/19/08	-0.244		President Bush Declared that TARP Funds to be Spent on Programs Paulson Deemed Necessary
02/24/09	-0.261		President Obama's First Speech as the President to Joint Session of U.S. Congress
05/10/10	-0.647 (-0.601)	0.003	European Policy-Makers Unveiled an Unprecedented Emergency Loan Plan
03/21/11	-0.277		Japanese nuclear reactors cooled down and situations in Libya tamed by unilateral forces
08/09/11	-0.433 (-0.370)	0.046	FOMC Statement Explicitly Stating a Duration for an Exceptionally Low Target Rate
10/27/11	-0.245 (-0.205)	0.034	European Union leaders made a bond deal to fix the Greek debt crisis
01/02/13	-0.432 (-0.427)	0.025	President Obama and Senator McConnell's encouraging comments on the "Fiscal Cliff" issue

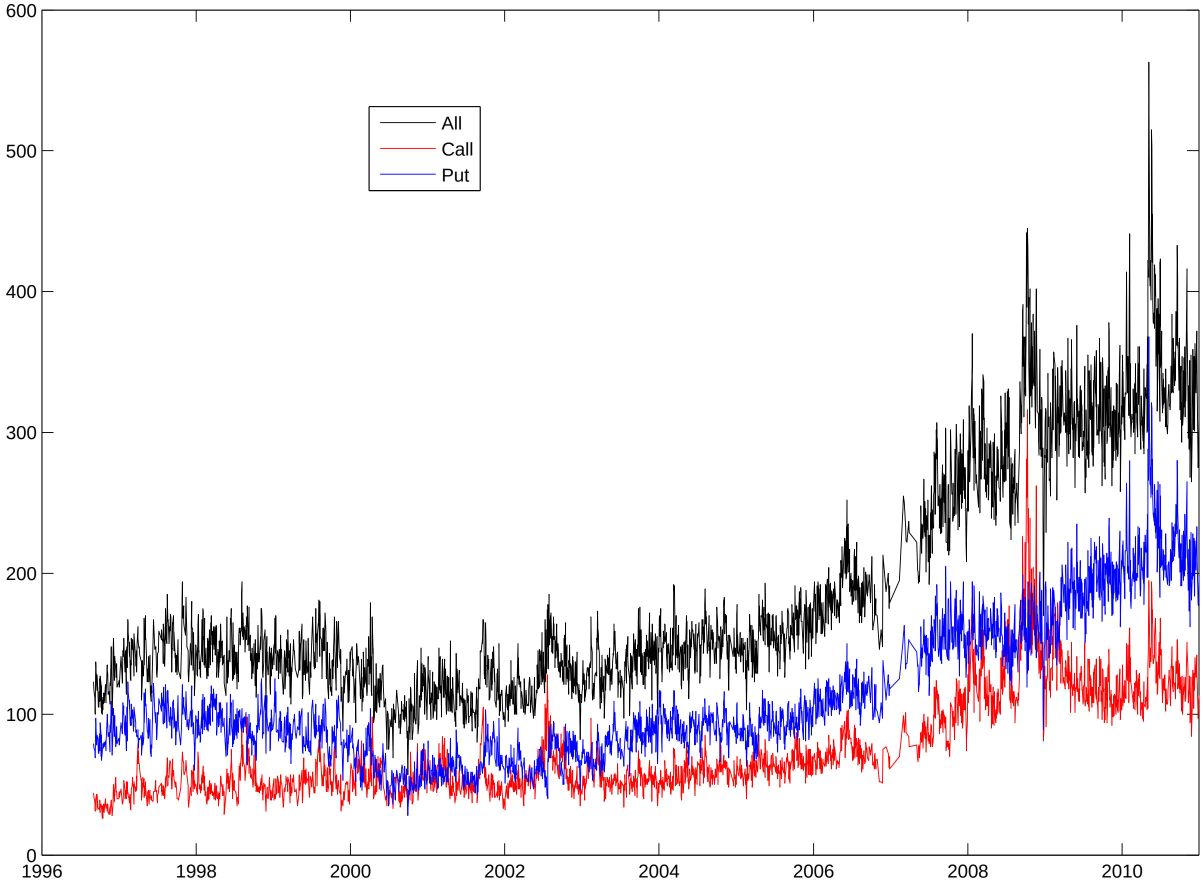
This table from Amengual and Xiu (2014) presents in the last column the events that may lead to the largest volatility drops in the sample. The first column is the date of the event. The second shows changes in estimated spot variance, whereas the third column is the returns of the index on the corresponding days.

Table A6: **Reaction of Variance and Skewness Risk Premia to Financial and Macroeconomic Announcements**

			VRP		VRP^U		VRP^D		SRP	
Booth Date	ΔVar	Δr	Change	Level	Change	Level	Change	Level	Change	Level
08/18/1998	-0.373	0.013	-0.0146	0.0964	-0.0059	-0.0045	-0.0132	0.1188	-0.0073	0.1234
09/01/1998	-0.722	0.035	-0.0292	0.1432	-0.0206	0.0066	-0.0210	0.1666	-0.0004	0.1600
09/08/1998	-0.526	0.021	-0.0404	0.1190	-0.0189	-0.0123	-0.0348	0.1498	-0.0159	0.1621
09/23/1998	-0.344	0.027	-0.0131	0.0980	-0.0105	-0.0241	-0.0088	0.1337	0.0017	0.1578
10/20/1998	-0.253	-0.007	-0.0160	0.0444	-0.0143	-0.0453	-0.0100	0.0875	0.0043	0.1328
08/11/1999	-0.266	0.008	-0.0169	0.0540	-0.0123	-0.0223	-0.0124	0.0815	-0.0001	0.1038
01/07/2000	-0.5	0.031	-0.0305	0.0137	-0.0028	-0.0341	-0.0328	0.0429	-0.0300	0.0770
03/16/2000	-0.266	0.037	-0.0174	-0.0209	-0.0118	-0.0553	-0.0130	0.0164	-0.0012	0.0717
04/17/2000	-0.373	0.032	-0.0183	0.0023	-0.0134	-0.0527	-0.0132	0.0426	0.0003	0.0953
10/19/2000	-0.241	0.018	-0.0190	0.0027	-0.0088	-0.0412	-0.0164	0.0340	-0.0076	0.0752
01/03/2001	-0.282	0.052	-0.0229	-0.0137	-0.0242	-0.0616	-0.0110	0.0285	0.0131	0.0900
05/17/2005	-0.275	0.01	-0.0063	0.0178	-0.0023	-0.0202	-0.0059	0.0372	-0.0036	0.0575
06/15/2006	-0.549	0.017	-0.0251	0.0201	-0.0141	-0.0260	-0.0209	0.0423	-0.0068	0.0683
06/29/2006	-0.295	0.016	-0.0154	0.0035	-0.0100	-0.0332	-0.0121	0.0275	-0.0021	0.0607
09/18/2007	-0.415	0.024	-0.0272	0.0059	-0.0100	-0.0357	-0.0252	0.0344	-0.0152	0.0701
10/14/2008	-0.489	-0.048	-0.0040	0.0054	-0.0106	-0.0730	0.0032	0.0641	0.0138	0.1371
10/20/2008	-0.426	0.033	-0.0628	-0.0012	-0.0280	-0.0943	-0.0558	0.0688	-0.0278	0.1631
10/28/2008	-0.313	0.075	-0.0518	0.0380	-0.0311	-0.1027	-0.0402	0.1187	-0.0091	0.2214
11/13/2008	-0.328	0.062	-0.0412	0.0071	-0.0253	-0.1270	-0.0322	0.0986	-0.0069	0.2256
05/10/2010	-0.647	0.003	-0.0631	0.0764	-0.0386	-0.0215	-0.0488	0.1058	-0.0102	0.1273
08/09/2011	-0.433	0.046	-0.0628	0.0754	-0.0365	-0.0143	-0.0504	0.0997	-0.0139	0.1140
10/27/2011	-0.245	0.034	-0.0240	-0.0447	-0.0184	-0.0953	-0.0165	0.0115	0.0019	0.1068

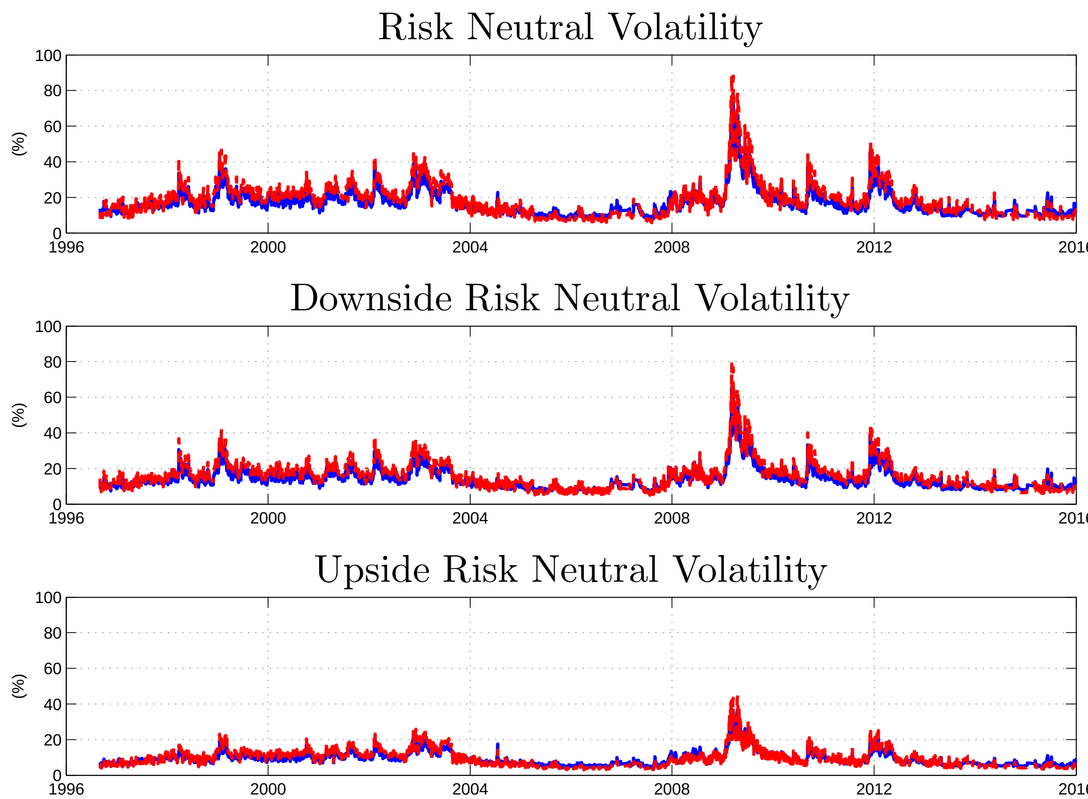
This table reports the reaction of the variance risk premium (VRP), upside variance risk premium (VRP^U), downside variance risk premium (VRP^D), and skewness risk premium (SRP) to the macroeconomic and financial news documented in Table A5. The table reports changes in conditional volatility (ΔVar) and S&P 500 returns (Δr) on the event day, as well as changes and levels of VRP, VRP^U, VRP^D, and SRP on the event date. A negative sign in the change of a risk premium signifies a decline on the arrival of a particular macroeconomic or financial announcement. A positive sign implies the opposite.

Figure A1: S&P 500 Put and Call Contracts per Day



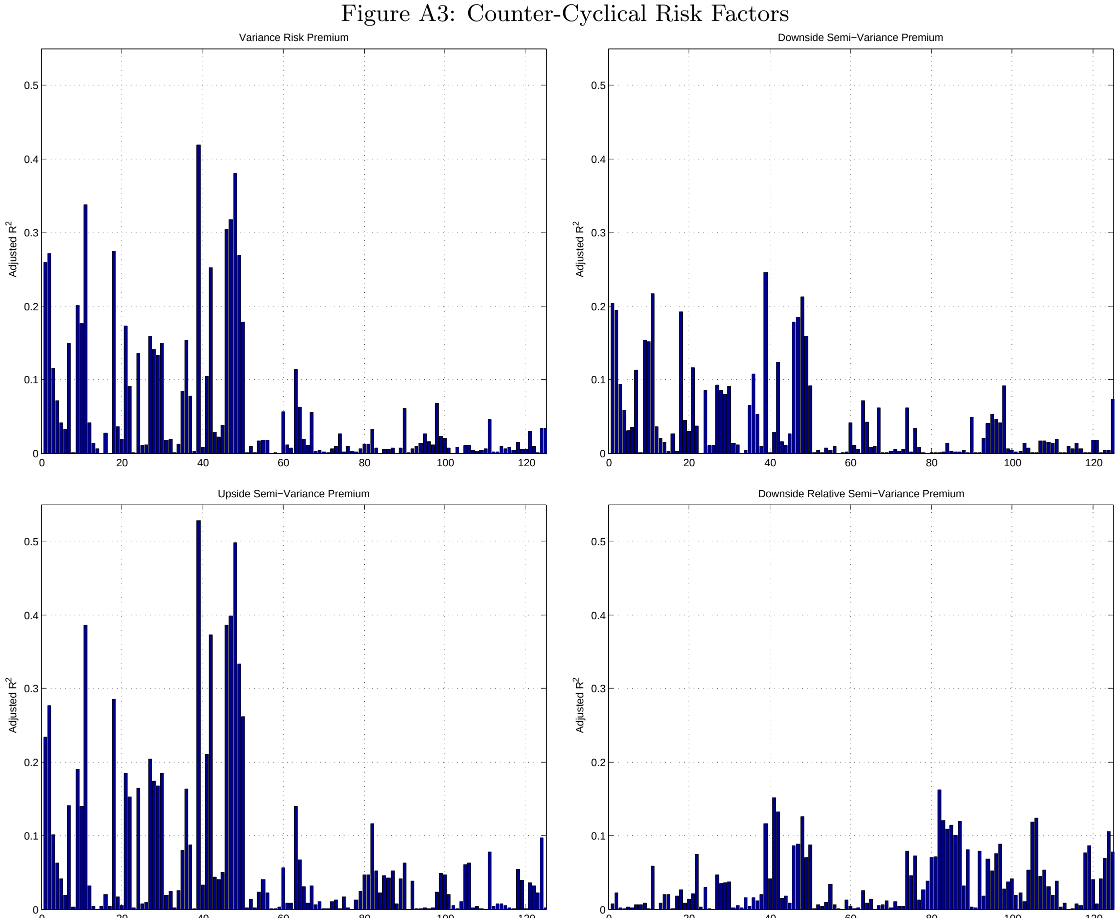
This graph show the number of outstanding put and call contracts written on the S&P 500 index per day for the 1996–2010 period. In addition, it plots the sum of put and call contract numbers. Source: OptionMetrics Ivy DB accessed via WRDS.

Figure A2: Risk Neutral Dynamics



This graph shows the time series of one-month (upside/downside) risk neutral volatility extracted from the traditional approach (blue line) and the dynamic hedge trading strategy (red line) from 1996 to 2016.

Figure A3: Counter-Cyclical Risk Factors



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