Index Option Anomalies: How Real Are They?

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Abstract

We examine empirical "puzzles" documented in several high profile studies of the market for S&P 500 index options, such as the overpricing of out-of-the money (OTM) put options and at-the-money (ATM) straddles. We find that without any exception the theoretical bases of these studies have ignored persistent features of the index option market data such as the wide bid-ask spreads for OTM options, the partial segmentation of the market for puts and calls, and the inconsistency of the parameter estimates for different maturity options. We present simple theoretical models that incorporate these features and are parsimonious in terms of other assumptions concerning the asset dynamics of the index and the simultaneous equilibrium of the underlying and option markets. We find that these puzzles disappear under such conditions and conclude that model error is probably responsible for these apparent anomalies.

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I. Introduction

In this paper we examine anomalies that have appeared in several high profile empirical studies in the index option markets. We focus on claims that OTM puts and ATM straddles are overpriced. We argue that this overpricing is due to the failure of the theoretical option pricing models used in the empirical analyses, which persistently ignore option market features such as wide bid-ask spreads for OTM options, weak integration of the markets for put and call options, and clear conditionality and maturity effects in option prices. We use empirical tests that recognize these features and show that there is no profitable trading for all risk averse investors implied by the alleged mispricing. Our results indicate that when puts exist in mispriced option portfolios it is the calls, rather than the puts, that are primarily responsible for whatever anomalies may exist in the observed market data.

The "overpriced OTM put" appears for the first time in Rubinstein's (1994, pp. 774-775) classic paper that first documented the existence of the implied volatility (IV) smile in S&P 500 index options for the post-1987 crash data. The main justification for this claim is the shape of the IV graph as a function of moneyness, which in the post-1987 crash period had the well-known downward slope when plotted against the ratio $\frac{K}{S_t}$ of strike to index price. This shape of the IV graph has persisted since then. For instance, Benzoni *et al* (2011) observed that over the post-1987 crash period till 2006 the deep OTM put options with a 90% moneyness ratio had an IV that was on average 8.21% higher than their ATM counterparts, which in turn had an IV that was higher by 1.33% than the in-the-money (ITM) options. Overpriced puts play a central role in, among others, Driessen and Maenhout (DM, 2007), Garleanu, Petersen and Poteshman (GPP, 2009), Bondarenko (2003, 2014), Santa Clara and Saretto (SS, 2009), and Chambers *et al* (CFLL, 2014), while Broadie, Chernov and Johannes (BCJ, 2009) claim that put overpricing can be explained by jump risk premiums and estimation risk. Some of these studies also present empirical data on ATM straddles' returns, which are also claimed to be anomalous.

Rubinstein formulated several conjectures about the sources of the smile, which was not present in the pre-1987 index option data. One of them was that the smile was due to "crash-o-phobia", a term that he identified (p. 784) with the left tail of the risk neutral distribution extracted from the option market, which is significantly fatter than the underlying return's physical or P-distribution. This "crash-o-phobia" was recently characterized as a "dark matter" in finance, defined by Ross (2015, p. 616) as the "very low probability of a catastrophic event and the impact that changes in that perceived probability can have on asset prices". More specifically, it is the inability of virtually the entire empirical research dealing with the pricing of rare events in the option markets to achieve a "reasonable" reconciliation of the implied rare event probabilities extracted from options to the observed historical frequency of such events in the underlying market. Although the option-implied return distribution is supposedly forward-looking and need not be the same as the one extracted from historical returns, it should not imply implausible statistical behavior that has never been observed in the real world.

Almost all option market studies, including those that claim put overpricing, ignore frictions or incorporate them only partially into their models.[1] This is a striking omission, given the fact that the index option market is characterized by very wide bid-ask spreads for OTM options that raise questions about the appropriate option price to be chosen from within the spread.[2] Most importantly, Rubinstein himself in the initial article documenting the smile had raised (1994, p. 778) the possibility that the volatility smile may have been due to various types of frictions. As he notes, the violations introduced by frictions into the Black-Scholes-Merton (BSM) model's assumptions "are the worst, because their effects are notoriously difficult to model and they typically lead only to bands within which the option price should lie".

Figure 1 plots the observed bid-ask spread for S&P 500 put options as a percent of its midpoint for each year of our data set. The chart shows the median of the 12 proportional spreads observed in each year of the 1990-2012 period for two degrees of moneyness and two maturities, ATM and OTM with $\frac{K}{S_t} = 0.93$ and 28- and 7-day maturities. The data for this important variable, widely used as an indicator of option market illiquidity, shows very clearly two effects, a moneyness effect and a maturity effect, with OTM and 7-day maturity options being the least liquid. To assess the importance of these spreads in the overpriced OTM put literature we note that a vertical spread of an ATM and an OTM put of 6% had an average negative return of slightly over -21% in BCJ and CFLL, as shown in Table 1 of the latter study. It is clear that much and perhaps most of that negative return would have vanished if the spread had been executed at the ATM ask price and the OTM bid price in several cases implied by the Figure 1 data.

More disturbingly, there are clear indications that the spread has increased over time for all maturities and degrees of moneyness: regressions of all spreads data (not just the annual medians) for the four time series in Figure 1 against a constant and a time trend show highly significant t-statistics for the latter, in the range of 3.20-6.46. The regression coefficients at the trend line imply an average increase in proportional spreads of 10 (20) basis points per year for ATM and 30 (80) for OTM 28-day (7-day) options. Surprisingly, this increase in the width of the spread for the shorter maturity, which is also present in the 14-day options, coincides with an increase in another variable that is associated with option market *liquidity*, the volume of trade, which is higher for the shorter maturities. In our data the ratio of the volume of the median non-market maker trades of the shorter maturities over the median 28-day volume of similar trades is 1.55 and 1.85 for the 14-day and 7-day puts respectively, with similar results for call options. These contradictory statistics raise serious issues for the measures of liquidity in the option markets that transcend the scope of this paper.

[Figure 1 about here]

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[1] An exception is Santa Clara and Saretto (2009), in which frictions under the form of margins play a central role in explaining the observed mispricing. In our case margins are not included in the analysis.

[2] See Perrakis (2017).

As the Rubinstein quote implies, the main drawback of studying empirically the frictionless option market in order to derive inferences about its equilibrium prices is the non-observability of the prices that are being studied.[3] For this reason most frictionless option market studies limit themselves to the OTM put and call options, most often by using the midpoints of the spreads and assuming that put-call parity (PCP) holds. Not only is such an assumption at variance with the observable facts, but it also produces logical inconsistencies within the frictionless models. Thus, if OTM puts are overpriced then adopting short positions should be highly profitable after adjusting for risk, as the above-cited literature argues that it actually happens. In turn, the PCP assumption implies that ITM *calls* are also overpriced: as GPP (2009, p. 4279) point out, “our theoretical results indicate that the demand from a put or a call with the same strike price and maturity should have identical price impact”. In fact Bondarenko (2014, Table I) presents empirical evidence that the option market is at least partially segmented: investing in long positions in ATM puts yields a negative and highly significant average monthly return of -0.39%, while long positions in ATM calls yield a positive but non-significant average monthly return of 0.04%. Further, Ioffe and Prisman (2013) report many problems with arbitrage violations when using the midpoint of the spread in order to represent the “true” option price, while Constantinides and Lian (forthcoming) present an equilibrium model for the market for index put options, in which it is stated clearly (pp. 8-9) that the model is not applicable to call options.

Our theoretical framework adopts the general methodology of the second degree stochastic dominance (SD) approach to European index call option pricing in the presence of proportional transaction costs introduced by Constantinides and Perrakis (CP, 2002) and extends it to put options and straddles/strangles. The SD approach incorporates the missing features of the “overpriced put” studies and is parsimonious in terms of other assumptions concerning the asset dynamics of the index and the simultaneous equilibrium of the underlying and option markets. All that it assumes is that there is a set of investors with portfolios holding only the index and the riskless asset, termed the index traders (IT). This assumption, which has also been used in several of the “overpriced put” studies, holds indisputably for the S&P 500 index, the underlying instrument in all the empirical studies discussed in this article. This index is arguably the most popular exchange traded fund (ETF) at a time when ETF’s are the instrument of choice for a drastically increasing share of investors’ portfolios. In the decade through the end of 2016 $1.4 trillion in new cash flow and reinvested dividends went into domestic equity index funds and ETF’s, while actively managed funds had a $1.1 trillion outflow during the same period.[4]

Given the set of IT investors, we derive an appropriately defined zero-net-cost option portfolio involving the option strategies whose potential mispricing we wish to examine, and add it to the index after purchasing/writing the options at their observed ask/bid prices. The only “overpricing” criterion recognized in SD is the existence of strategies that can improve the expected utility of all risk averse IT investors. This criterion, which corresponds to positive risk-

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[3] A colorful way of expressing this is in Rubinstein (1985, p. 465).

[4] See Bogle (2005), as well as the article “The end of active investing?”, *Financial Times*, January 20, 2017, at https://www.ft.com/content/6b2d5490-d9bb-11e6-944b-e7eb37a6aa8e.

adjusted expected returns for all risk averse IT, is also consistent with common sense and professional practice. If such strategies do not exist then the options are correctly priced and the resulting option trader (OT) portfolio should not stochastically dominate the IT investment. This, of course, does not preclude the possibility that *some* IT investors could profit from these OT portfolios. Nor does it preclude the possibility that all risk averse investors could profit from option portfolios containing puts; in such cases the short puts are simply minor components in the overall mispriced portfolios.

Our tests are both in-sample and out-of-sample and allow us to examine the ATM straddles and the vertical spreads that include puts, which play an important role in the BCJ and CFLL results. In our empirical work we use historically observed data modified by observable factors at the time the portfolios are formed to forecast the distribution of the underlying at option expiration that may include jump risk components. Such conditional forecasts allow us to verify whether there is in-sample dominance of the OT portfolio independently in every cross section. They also reduce the error by avoiding the reliance on parameters extracted from fitting a specific asset dynamics model to a long time series. Once all dominating OT portfolios are found the resulting standardized time series of OT wealth at option maturity is compared to the corresponding IT series in an SD test that is completely out-of-sample and model free, since it verifies whether the distribution from which OT is drawn does not dominate the corresponding IT series' distribution.

Our base case results are for 28-day maturity options, which appear in almost all previous studies. We also use 14- and 7-day maturity options, given the fact that empirical evidence from the frictionless equilibrium models strongly suggests that fitting the same option pricing model yields different coefficients for long and short maturities.[5] For OTM put options we find in all cases that there are few cross sections with overpricing when options trade at their bid and ask prices and the distribution includes jump components. For ATM straddles and strangles we find many more overpriced cross sections with jump components, but the actual returns of these strategies are not significantly higher than the observed IT returns, thus emphasizing the importance of estimation risk. Further, we show that whatever dominance may exist in the straddles comes overwhelmingly from OTM call options, thus confirming their importance as a source of possible anomalies, already shown in CCJP (2011), and in Constantinides, Czerwonko and Perrakis (CCP, 2017).

The main disadvantage of SD is that it cannot accommodate independent volatility risk wherever it may exist in the IT utility function. Such a risk, however, is relevant only as a possible explanation of excess returns of an option strategy, which do not exist in our cases. Volatility risk has also been ignored as irrelevant for short term options in a recent empirical study by Andersen *et al* (2017). As a robustness check, we apply the conventional CAPM-based risk and return criteria to the policies of selling naked OTM put portfolios and find that our SD results are consistent with these criteria as well. In the next section we derive SD-implied relations for short

[5] See Bakshi, Cao and Chen (1997), and Andersen, Fusari and Todorov (2017, p. 1350).

put and ATM short straddle mispricing. Section 3 presents the data, Section 4 the results and Section 5 concludes.

II. Stochastic Dominance Bounds

Let S_t denote the current value of the index and S_T its value at option maturity *T*. The IT investors hold a portfolio of the underlying index and a riskless bond, which they restructure every period in order to maximize the utility of terminal wealth at a given finite horizon much longer than *T*. We assume that there are no transaction costs on the riskless asset, and let R denote the riskless return and k the one-way transaction cost rate in trading the underlying. At any intermediate time point the value function is a concave function of the holdings of the amounts of the two assets in the IT portfolio.

This model, analyzed for the first time in a seminal paper by Constantinides (1979), was shown to imply for a wide class of dynamics of the risky index a restructuring policy that includes a no trade (NT) zone. As the name implies, the IT investor does not trade as long as the portfolio stays in the zone, while she restructures it to the nearest NT boundary when it moves outside it. Constantinides (1986) derived closed form solutions for the NT zone and the value function for a constant relative risk aversion utility function under constant volatility diffusion index dynamics and an infinite horizon. Czerwonko and Perrakis (2016) extended the results numerically to jump-diffusion for a given finite horizon. The bounds developed here, which follow closely the CP and CCP studies, do not depend on a particular utility function. Instead, it is assumed that the IT trader starts somewhere in the middle of the NT zone and stays in that zone till option expiration. This assumption is almost always satisfied for the short maturities examined here: in Czerwonko and Perrakis (2016) the observed intermediate trading in numerical simulations is insignificant under all realistic parameter values, even for a two-year horizon.

To apply SD we overlay the IT two-asset portfolio by a zero net cost option portfolio chosen in such a way that the OT portfolio dominates the IT portfolio if the expected net option portfolio payoff at maturity after everything is transferred to the index account is non-negative. For the zero cost condition OT borrows to finance the net outlays of the option strategies and repays at option maturity. We use the fact that the IT subjective stochastic discount factor, the partial derivative of the value function with respect to the index at option maturity, is monotone non-increasing in S_T by the concavity of the value function. An additional requirement for SD is that the wealth of OT exceeds IT at the left tail and that the graphs of the two portfolios' wealth intersect at a single point.[6]

Overpriced OTM puts

We examine OTM put overpricing relative to their ATM counterparts in the context of SD by adopting modified versions of zero net cost vertical spreads in order to form the OT option portfolio that will be added to the index. Specifically, let the OT option portfolio consist of one

[6] These conditions were first presented in the context of SD by Rothschild and Stiglitz (1970).

long ATM/ITM put option with strike price K_1 and purchase price P_{1a}, and $\beta \geq 1$ short OTM puts with strike price K_2 and write price P_{2b}. At option maturity T such an option portfolio should have a nonnegative value when the underlying index price attains its minimum at $S_T = S_T^{\min}$. The portfolio value then either stays constant or rises in S_T with slope $\beta - 1$ till the value $S_T = K_2$, at which point it decreases till $S_T = K_1$, becoming flat thereafter. The payoff at T is equal to $\left(\beta P_{2b} - P_{1a}\right) R - \beta\left(K_2 - S_T\right)^+ + \left(K_1 - S_T\right)^+$, which is initially nonnegative, becomes zero at a value $\hat{S}_T \in (K_1, K_2)$ and is negative thereafter. Hence, to transfer the payoff to the index account we must divide it by $1+k$ for $S_T \leq \hat{S}_T$ and by $1-k$ otherwise. The OTM option is correctly priced by the observed P_{2b} if the following problem (2.1) has a feasible solution for all $\beta \geq 1$. Feasibility implies that there is no zero net cost vertical spread involving these two put options that has a positive expected payoff and implies second order SD of the OT over IT portfolios.

$$K_1 - S_T^{\min} - \beta\left(K_2 - S_T^{\min}\right) - (P_{1a} - \beta P_{2b}) R \geq 0$$
$$E\begin{bmatrix} \dfrac{\left(\beta P_{2b} - P_{1a}\right) R - \beta\left(K_2 - S_T\right)^+ + \left(K_1 - S_T\right)^+}{1+k}, \; S_T \leq \hat{S}_T \\ \dfrac{\left(\beta P_{2b} - P_{1a}\right) R - \beta\left(K_2 - S_T\right)^+ + \left(K_1 - S_T\right)^+}{1-k}, \; S_T > \hat{S}_T \end{bmatrix} \leq 0 \quad . \tag{2.1}$$

We transform the feasibility of the problem (2.1) into an upper bound for P_{2b} by using the function $I(z) \equiv \begin{cases} 1/(1+k), & z \leq 0 \\ 1/(1-k), & z > 0 \end{cases}$. (2.1) is then feasible if the following inequality holds

$$P_{2b} \leq \overline{P}_2 = \frac{P_{1a}}{\beta} + \frac{E[(K_2 - S_T)^+ I(S_T - \hat{S}_T)]}{RE[I(S_T - \hat{S}_T)]} - \frac{E[(K_1 - S_T)^+ I(S_T - \hat{S}_T)]}{\beta RE[I(S_T - \hat{S}_T)]} \quad . \tag{2.2}$$

In the frictionless economy option bid and ask prices are equal and equation (2.2) becomes

$$P_2 \leq \overline{P}_2 = \frac{P_1}{\beta} + \frac{E[(K_2 - S_T)^+]}{R} - \frac{E[(K_1 - S_T)^+]}{\beta R} \quad . \qquad (2.2)'$$

Note that (2.2)' does not require put-call parity. In that economy it can be shown that the put price P_1 always exceeds the discounted expectation, implying that the bound tightens when the parameter β decreases towards 1. The same is also true for the bound in (2.2) for reasonably small values of the cost parameter k. In practice, we solve the problem $Min_\beta \overline{P}_2$ as given by (2.2) or (2.2)', subject to the constraint in the first line of (2.1).

If the system (2.1) is feasible at the optimally determined value of β then the OTM option is priced correctly in the economy that recognizes frictions. If (2.1) is infeasible then there is an in-sample costless vertical spread that creates SD for the OT investor in that cross section. If a sufficient number of such dates is present in our data for an option with a particular maturity and degree of moneyness then the mispricing can also be verified out of sample with the realized option payoffs and constitutes a tradable anomaly. The same also holds for SD in the frictionless economy, for which we verify the feasibility of (2.1) after setting $k = 0$ and replacing the put options' bid and ask prices by the corresponding midpoints of their bid-ask spreads. The resulting bound (2.2)' is clearly lower than the one in (2.2), implying that the OTM put may be correctly priced under frictions but not in the frictionless economy.

Overpriced short straddles

We now examine whether such put overpricing can be justified in the case of short ATM straddles, as claimed by DM, BCJ and CFLL. We control left tail risk in the OT portfolio by shorting an amount β of the ATM put at a price P_b and one short call at a price C_b, chosen to satisfy the following conditions, the counterpart of (2.1):

$$-\beta(K - S_T^{\min}) + (\beta P_b + C_b)R \geq 0$$
$$E\begin{bmatrix} \dfrac{(C_b + \beta P_b)R - \beta(K - S_T)^+ - (S_T - K)^+}{1+k}, \ S_T \leq \hat{S}_T \\ \dfrac{(C_b + \beta P_b)R - (S_T - K)^+}{1-k}, \ S_T > \hat{S}_T \end{bmatrix} \leq 0 \quad . \tag{2.3}$$

From this we get the ATM put upper bound, given the corresponding call bid price:

$$P_b \leq \overline{P} = -\frac{C_b}{\beta} + \frac{E[(K - S_T)^+ I(S_T - \hat{S}_T)]}{RE[I(S_T - \hat{S}_T)]} + \frac{E[(S_T - K)^+ I(S_T - \hat{S}_T)]}{\beta RE[I(S_T - \hat{S}_T)]} \quad . \tag{2.4}$$

In the absence of frictions the bound becomes

$$P_b \leq \overline{P} = -\frac{C_b}{\beta} + \frac{E[(K - S_T)^+]}{R} + \frac{E[(S_T - K)^+]}{\beta R} \quad . \qquad (2.4)'$$

As in the previous case, this last bound does not require put-call parity.

If the call bid is correctly priced according to the SD bounds derived in CP (2002) then the right-hand-sides (RHS) of (2.4) and (2.4)' are increasing functions of β,[7] and SD put upper

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[7] It is easy to see that this holds approximately for short maturity options if C_b satisfies the CP (2002, Proposition 1) upper bound. If the call is overpriced then the SD put upper bound may not exist, since the RHS of (2.4) or (2.4)' may be negative.

bounds $\overline{P}$ exist when trading at the observed bid prices or the bid-ask midpoints respectively, whose violations create tradable anomalies within the corresponding set of assumptions. The tightest such bound corresponds to the highest value of β satisfying the first feasibility condition in (2.3).

From (2.2)-(2.2)' and (2.4)-(2.4)' it is clear that the derived bounds contain as special cases for $\beta = 1$ the vertical spreads and short straddles of BCJ and CFLL, *provided* the left tail conditions in (2.1) and (2.3) are satisfied. These conditions can easily be relaxed within our SD formulation to allow for some left tail risk, but in such a case there may be risk averse investors who will not prefer OT over IT. This issue is examined in our robustness checks in Section 4.

III. Data

The main empirical results are based options on the S&P 500 index that expire on the third Friday of each calendar month (hereafter monthly options). We obtain prices of monthly S&P 500 European puts and calls 28, 14, and 7 days to maturity from the Chicago Board Options Exchange (CBOE) tape with intraday quotes from January 1990 to February 2013, yielding 278 dates. The 14-day options are the same 28-day options with respect to moneyness and expiration date but observed 14 days to expiration. The 7-day options are the same 28-day options with respect to moneyness and expiration date but observed seven days to expiration.

We delete obvious data entry errors such as multiple or missing data or bid prices exceeding the ask prices. We filter the data by checking that the put-call parity and convexity with respect to the strike price under transaction costs in the index and bid-ask prices of options hold. We conservatively use ten basis points as a one-way transactions cost rate for index trades.[8] We also apply liquidity filters to guarantee that only options that can be traded under realistic conditions enter into our choice set. We include call prices with bid prices at least 15 cents and moneyness within 0.96-1.08. For put options we discard all options more than 4% in the money but admit all options with bid prices of at least 15 cents. This asymmetry in admitting put options is justified by the relatively higher liquidity of OTM puts. Lastly we only admit quotes updated within the past 15 minutes. After applying our filters we exclude four dates on which we cannot find at least three call options and three put options available for selection in our portfolios.

We build the zero-net-cost portfolios at 3:00 PM SET, one hour before market closing, thus avoiding possible distortions of the closing market inherent in end-of-day prices. We execute the trades 15 minutes later for these same options which were found to be optimal to include in the portfolio, readjusting their weights with the same objective as at the 3 PM portfolio derivation time for the data observed one minute before the actual trade. Since SPX options are exercised at the opening price of the terminal date, we collect the exercise proceeds by using the opening value of the index and ascribe the proceeds to the ending position of the index.

[8] Note that the lower this rate the more arbitrage violations are found. With no transaction costs for the index and with trading in options at the bid-ask midpoint virtually all options prices are rejected because of arbitrage violations; see also Ioffe and Prisman (2013).

We derive the index price from the cost-of-carry relation between the observed spot index and its nearest-to-maturity futures contract as follows. We use a data set from Tick Data. We estimate the implied index price by recording implicit cost-of-carry coefficients from observed spot-futures pairs for one hour before our estimation or trade time in one-minute intervals. We then use the median value of this coefficient to convert the most recent futures value into the implied spot index price. Note that as of 2006 the increased quality of reporting of the index price renders the difference between the cash index and its derived price negligible. We derive the dividend yield by using cash daily payouts obtained from Standard and Poor. For the interest rate we use the three-month constant maturity T-bill rate obtained from the Federal Reserve Economic Data. We assume a one-way transaction costs rate for the underlying of to 0.1%, reflecting its average value over the period of the study.

IV. Results

For our results we use two alternative P-distributions, one truncated lognormal and the other with excess skewness and kurtosis to account for the presence of jump components. In the absence of jump risk the index price is assumed to follow a truncated lognormal distribution with average cum dividend return equal to 4%, plus the annualized risk-free rate, as per the long-term historical average. We truncate it at the left tail by setting the value $S_T = S_T^{\min}$ to 80% of the underlying price in one week, and adjust the other maturities by setting $S_T^{\min} = S_t[1-0.2\sqrt{\frac{T}{7}}]$, where T denotes the maturity in days. We forecast the index return volatility till the expiration date by using the CBOE VIX volatility adjusted by the mean forecast difference between the VIX and the realized volatility for the period 1986 to the current date. Both the VIX and the realized volatility of daily returns are measured in four-week intervals without overlap, with the latter quantity defined as the square root of 252 times the mean squared daily return. The amount by which the VIX exceeds the realized volatility (the negative volatility risk premium) is relatively stable over time, about 4.5-4.8%. Finally, we include jump risk by setting the excess kurtosis of the distribution at 0.5 and skewness at -0.5, approximately equal to those of the index.

Once the overpriced option portfolios, whether put vertical spreads or straddles, have been identified in-sample we verify whether the results are robust to estimation risk. We compare the IT and OT portfolios at the option maturity and generate two time series of realized returns, which we compare in several ways. First, we derive bootstrap *p*-values for a negative mean excess return. Second, we apply the Davidson (2009) and Davidson-Duclos (DD, 2013) test for restricted second-order stochastic dominance. This test is model-free, since it compares two time series and only requires that the observations in each series be serially uncorrelated. The test is based on the null hypothesis of non-dominance, as opposed to several other tests where the null is dominance and would provide a relatively weak evidence by finding a high *p*-value for the null since by construction they do not reject anything. DD demonstrate that the null of non-dominance cannot, in principle, be rejected over the entire joint support for the two examined prospects even if it exists in population; therefore, some points in the tails of this joint support are removed from the search for the minimal *t*-stat which forms the basis of the bootstrap procedure in the DD test.[9]

[Table 1 about here]

Table 1 shows the effects of frictions and jump risk on the "overpriced OTM put options" hypothesis. We concentrate on the put option with moneyness $\frac{K_2}{S_t} = 0.93$, which appears to be the most overpriced in GPP (2009, Figure 2, p. 4282). For each cross section and each maturity in our data we verify the feasibility relation (2.1) for the optimally determined β, as well as its frictionless counterpart, using the nearest to ATM put with a sufficiently low ask price to create a violation of the upper bound (2.2) or (2.2)' if any such put exists. Column 2 indicates the number of infeasible dates out of the total time series of 278, those for which there is a violation of the corresponding bound in each case.

As the feasibility column shows, the violations of the OTM put upper bound are sharply higher in all cases in the frictionless economy, as expected. More surprising is the strong effect of the inclusion of jump components in the assumed P -distribution, which reduces everywhere the bound violations, especially for the shorter maturities and in the presence of transaction costs. In fact the 7-day maturity, with only about 6.1% of violating cross sections, is approximately correctly priced in spite of the high profitability of trading the OT portfolio in these cross sections, shown in column 3. This effect lends at least partial support to the explanation given by BCJ (2009) for put overpricing, who attribute it to jump risk and estimations error: the inclusion of jump risk and the elimination of model error in pricing it by SD also eliminates a large part of the overpricing.

Although the SD bound was efficient in identifying in-sample overpriced OTM puts, the overall evidence when we use all the cross sections, shown in-sample in column 5 and out-of-sample in column 6, tells a different story. The 0.93 OTM put may have been overpriced in our time series with respect to its ATM counterpart, but the resulting OT portfolios were not overpriced with respect to the index. Some overpricing appears in the frictionless case for the two shorter maturities when jump risk is incorporated into the P -distribution, but even here the excess return of the OT portfolio is not different from 0.

[Table 2 about here]

[Table 3 about here]

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[9] The DD test considers a minimal *t*-stat in the restricted support. If there is no restriction in the left tail, a minimal *t*-stat is equal to one by construction. Without any restriction in the right tail, the minimal *t*-stat in cases like ours will usually correspond to the difference in means, whose statistical significance is too strong a condition for SD. See also CCJP (2011), where the application of the DD test in a similar situation is described in detail and for evidence that the test is conservative in rejecting a false null.

Tables 2 and 3 show the SD-violating overpriced puts imbedded in short ATM straddles and strangles respectively with and without frictions according to (2.4) and (2.4)'. The OT portfolios all correspond to one short call and $(1\text{-N Put})^{-1}$-1 short puts. Given the importance of jump risk in Table 1, we show results only for the mixed jump-diffusion P-distributions. We use straddles at or near ATM, as well as two strangles with both OTM calls and puts near the money. The tables show the OT portfolio results and separately the contributions of its put component.

Both tables show that for the degrees of moneyness $\frac{K}{S_t}$ equal to 0.99 and 1, namely the ones corresponding to OTM and ATM puts, the straddles series contain a large number of in-sample violations of the put bound that yield a positive in-sample excess return over IT. These returns, however, are highly volatile, yielding negative out-of-sample returns and rejections of the DD stochastic dominance tests. This is true for all maturities in the presence of frictions and all but two of the six frictionless cases. The situation improves somewhat but not by very much in the two cases where the straddle contains ITM puts and an OTM call, and also in the two strangles where we short OTM puts and one OTM call. Here the SD tests reject the null of non-dominance for all maturities, both with and without frictions. Nonetheless, the excess returns of the OT portfolios are almost always not significantly different from 0 as shown by their *p*-values, with only two exceptions in the shortest maturity of the frictionless case.

Most important of all, in the two tables' results and in all cases the value of β, the amount of short put included in the straddle/strangle that produces the tightest bound and the highest excess return, is very low, much lower than 10% of an option, especially in the cases where the out-of-sample tests reject the non-dominance null. This implies that the rejections of the null were almost exclusively driven by the call component of the OT portfolio. This is in full agreement with the CCP (2017) results, where short calls were the most important component of the OT portfolios, and also with the CCJP (2011) mispriced call option results, which were for American index futures options.

Our last empirical results examine put overpricing after relaxing a key assumption of SD, which mandates that the left tail of the graph of the OT wealth lie above the corresponding left tail of IT. This was achieved in the OTM put upper bounds (2.2) and (2.2)' by including a long position in an ATM put. For an IT holding of one unit of the index the resulting *net* exposure to the short OTM put is equal to $\beta - 1$, a value that varies for each cross section since it depends on the price of the long ATM put. Suppose that we sell unhedged OTM puts, and allow the OT wealth to fall below IT at the left tail. We limit the risk by limiting the number of short puts per unit index held by IT in such a way that the OT wealth falls to zero only when the index decrease within the option maturity time is unrealistically high; we set this decrease at 50%. . For this, we divide the OTM put range of 0.91-1 into three overlapping subranges and sell in each subrange put portfolios such that their equally weighted strike prices exceed the underlying index by a factor of two. For instance, for the range 0.95-1.00 and index value 1 the equally weighted strike price is 0.975 and we trade 2/0.975 such portfolios.[10] The results are shown in Table 4.

[Table 4 about here]

The table shows in the first line for each maturity the annualized observed excess returns of the OT portfolios over the riskless rate, and in the following lines the corresponding volatilities, Sharpe ratios, maximum observed losses and the results of a CAPM regression of the payoffs on the index as a state variable, namely the alphas and their p-values. The results in the table show little evidence for put mispricing, both under transaction costs and in the frictionless case, since the CAPM explains well the short put portfolio returns in most cases. In particular, for the key 28-day maturity and the realistic case with transaction costs, the extra OT return of 2.44% over IT for the range 0.95-1.00 also involves a much higher maximum loss, while if we halve the exposure and sell 1/0.975 portfolios the excess return of OT falls below that of IT. Further, we observe that the results contradict the common wisdom of mispriced OTM puts since the portfolio performance improves when the moneyness range moves closer to ATM. Last, there is a clear conditionality and maturity effect, since the returns increase and the risk inclusive of minimal return decreases as the maturity gets shorter.

V. Summary and Conclusions

The overpriced put and ATM straddle anomalies in the index options market have persisted in the financial literature for more than 20 years and are still being treated as puzzles. This paper has traced the origins of these studies, which has also other related aspects such as the non-monotone pricing kernel hypothesis.[11] The striking observation that one can make about this literature is how similar almost all of the studies have been in their modeling assumptions, in spite of the fact that these have not been particularly helpful in explaining the puzzles. The one exception is Santa Clara and Saretto (2009), who point out the importance of margins in explaining the put results; our own results do not depend on margins, which have not been included in our analysis. As we have noted, conspicuously absent from the other models are any concerns about well-known features of the financial markets such as the wide bid-ask spreads in the index option markets, the partial segmentation of the market for calls and puts and the differing option market-implied asset dynamics’ coefficients for short maturities.

The SD approach that we have applied in this paper is significantly more general in its assumptions than the theoretical models and the data used in the studies discussed in this paper. For instance, in DM (2007) the overpricing claims for both puts and straddles are established by introducing optimally these option positions together with the underlying and cash into constant

[10] Note that the industry standard for portfolio managers is to keep this ratio to 1. For such a ratio average and minimal returns and alphas would be approximately divided by two, while the Sharpe ratios and p-values would not change.

[11] This hypothesis was first expressed by Jackwerth (2000). For its implications for the efficiency of the frictionless market equilibrium see Beare (2011) and Beare and Schmidt (2016).

relative risk aversion (CRRA) utilities and observing whether the overpriced options had significantly negative coefficients. Their results show, by comparing their Tables II and VIII, that the optimal weights for the negative put and straddle positions become smaller when frictions are included. More to the point, DM did not use the actual option bid-ask spreads observed in their data but the average reported spreads in the study of Bakshi, Cao and Chen (BCC, 1997), which were extracted from observed spreads at the last daily quote of the option market over the three years from mid-1988 to mid-1991. These spreads, 4% for ATM and 6% for 96% OTM puts, are far lower than the ones observed in our data of 6.8% for ATM and 10.2% for 97.5% OTM puts reported in Perrakis (2017), and the more than 15% for the 93% OTM shown in Figure 1. These spreads are based on a longer data record that contains as a subset most of the data used by DM; moreover, the evidence shows that the spreads have increased over time. The other cited studies use model prices and/or ignore or minimize the importance of the bid-ask spreads in evaluating whether the options are overpriced, as in Bondarenko (2014, pp. 9-10).

Summarizing, our results show that generalized “put overpricing” appears nowhere in our data, implying that an option position including only puts will not be optimal for all risk averse investors. These statements do not exclude the possibility that there are individual risk averse investors and/or investors that trade on the basis of preference functions that contain behavioral factors who may profit from short put and/or straddle positions, for instance by choosing OTM short put portfolios that offer their preferred risk-return combinations. This is in striking contrast to the results in CCJP (2011) and CCP (2017), where *all* investors will profit from suitably chosen positions irrespective of their risk aversion levels. The same lack of mispricing is true of short straddles, where symmetry in the numbers of puts and calls is clearly inferior to portfolios including a much larger position in short calls than short puts for *all* risk averse investors. Note also that the short call positions reduce the delta in the combined index-option portfolio position and, therefore, reduce the importance of priced volatility factors in assessing excess returns of OT over IT wherever these appear.

Last, our empirical evidence shows that there is a clear conditionality and maturity effect in the priced options, since the shorter maturities seem to be more prone to option mispricing, notwithstanding their high liquidity. This is consistent with BCC (1997), who had had found that fitting the SV model to shorter term options yielded significantly different coefficients than when fitting it to the entire universe, and the more recent evidence of CCP (2017), where the mispriced portfolios were significantly more profitable for short maturity options. This, as well the documented increase of the bid-ask spreads over time, are issues that require further study, but that also illustrate the pitfalls of extracting inferences from models whose coefficients are estimated by fitting them to frictionless option data from all maturities.

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Table 1

OTM Put Overpricing by Violations of the Modified Vertical SD Spread Bound, 1990.01-2013.02

The table presents the number of cross sections violating the SD OTM put upper bound with and without frictions. The long put is the nearest to ATM option for which the bound is exceeded. All option portfolios were normalized to the total turnover of one option. Expected returns were derived for all observations; in case of infeasibility the lowest in absolute value negative return was used. The Sharpe ratio for the index for the maturities of 28, 14 and seven days was 0.55, 0.56 and 0.95, respectively. There were 278 observation dates in total.

T	Feasibility violations	μ_{OT}	Sharpe R.	$E[\mu_{OT}-\mu_{IT}]$	$\mu_{OT}-\mu_{IT}$	*p*-value for $\mu_{OT}-\mu_{IT}<0$	DD test *p*-value 5% trim	DD test *p*-value 10% trim
	Lognormal with Tr. Costs							
28	104	10.98	0.52	-0.49	-1.20	0.987	1	1
14	76	12.55	0.61	-1.04	-0.22	0.610	1	1
7	31	21.35	1.00	-2.28	-0.05	0.527	1	1
	Lognormal w/o Tr. Costs							
28	146	11.28	0.55	0.14	-0.90	0.938	1	1
14	130	11.88	0.59	-0.03	-0.88	0.828	1	1
7	125	21.33	1.11	-0.31	-0.07	0.521	1	1
	Ex. Kurtosis of 0.5, Skewness of -0.5 with Tr. Costs							
28	54	10.61	0.47	-0.99	-1.57	1	1	1
14	31	12.53	0.56	-1.64	-0.24	0.664	1	1
7	17	21.66	0.98	-2.85	0.26	0.360	0.073	0.013
	Ex. Kurtosis of 0.5, Skewness of -0.5 w/o Tr. Costs							
28	107	11.51	0.55	-0.36	-0.67	0.903	1	1
14	95	12.87	0.64	-0.53	0.10	0.467	0.304	0.069
7	95	21.71	1.07	-0.77	0.32	0.420	0.315	0.107

Table 2

Put Overpricing by Violations of the Straddle and Strangle Implied SD Spread Bound with Frictions, 1990.01-2013.02

The table presents the number N Viol. of cross sections violating the SD put upper bound implied by straddles and strangles with the indicated degree of moneyness. All option portfolios were normalized to the total turnover of one option. Expected returns were derived for all observations; in case of infeasibility the lowest in absolute value negative return was used. The Sharpe ratio for the index for the maturities of 28, 14 and seven days was 0.55, 0.56 and 0.95, respectively. There were 278 observation dates in total.

T	N Viol.	N Put (%)	$ Put (%)	μ_{OT}	Sharpe Ratio	$E[\mu_{OT}-\mu_{IT}]$	μ_{PUT}	$\mu_{OT}-\mu_{IT}$	*p*-value for $\mu_{OT}-\mu_{IT}<0$	DD test *p*-value 5% trim	DD test *p*-value 10% trim
					0.99 Straddle						
28	236	5.76	3.34	11.15	0.64	1.63	0.23	-1.03	0.722	1	1
14	239	5.99	3.17	11.14	0.65	2.18	0.45	-1.62	0.713	1	1
7	255	7.04	3.33	17.31	0.97	5.11	1.13	-4.09	0.815	1	1
					ATM Straddle						
28	231	4.30	4.15	12.02	0.67	1.85	0.16	-0.15	0.536	1	1
14	234	4.23	4.25	11.63	0.65	2.61	0.34	-1.14	0.671	1	1
7	254	4.39	4.92	20.27	1.13	6.38	0.71	-1.13	0.621	1	1
					1.01 Straddle						
28	223	3.00	5.16	12.67	0.68	1.78	0.12	0.50	0.339	0.245	0.052
14	226	2.98	6.00	13.01	0.75	4.37	0.33	0.25	0.444	0.113	0.013
7	252	2.54	7.09	22.87	1.21	5.48	0.49	1.47	0.309	0.044	0.002
					1.02 Straddle						
28	218	2.06	6.36	13.28	0.69	1.50	0.05	1.10	0.140	0.079	0.003
14	221	1.65	7.82	13.14	0.69	2.69	0.16	0.37	0.401	0.008	0.000
7	248	1.69	9.83	23.36	1.21	6.06	0.17	1.97	0.227	0.008	0.000
					0.99/1.01 Strangle						
28	224	3.11	3.27	12.78	0.69	1.79	0.09	0.61	0.309	0.220	0.056
14	227	3.09	3.35	12.98	0.76	4.41	0.29	0.21	0.451	0.114	0.015
7	252	2.68	3.32	22.96	1.22	5.54	0.48	1.56	0.302	0.046	0.004
					0.98/1.02 Strangle						
28	218	2.18	2.59	13.26	0.70	1.51	0.04	1.08	0.149	0.080	0.004
14	221	1.99	2.56	13.56	0.75	3.85	0.19	0.79	0.330	0.014	0.000
7	249	1.95	2.42	23.35	1.23	7.53	0.13	1.95	0.240	0.024	0.000

Table 3

Put Overpricing by Violations of the Straddle and Strangle Implied Frictionless SD Spread Bound, 1990.01-2013.02

The table presents the number N Viol. of cross sections violating the SD put upper bound implied by straddles and strangles with the indicated degree of moneyness. All option portfolios were normalized to the total turnover of one option. Expected returns were derived for all observations; in case of infeasibility the lowest in absolute value negative return was used. The Sharpe ratio for the index for the maturities of 28, 14 and seven days was 0.55, 0.56 and 0.95, respectively. There were 278 observation dates in total.

T	N Viol.	N Put (%)	$ Put (%)	μ_{OT}	Sharpe Ratio	$E[\mu_{OT}-\mu_{IT}]$	μ_{PUT}	$\mu_{OT}-\mu_{IT}$	*p*-value for $\mu_{OT}-\mu_{IT}<0$	DD test *p*-value 5% trim	DD test *p*-value 10% trim
					0.99 Straddle						
28	256	6.20	3.48	10.97	0.67	2.54	0.36	-1.20	0.742	1	1
14	257	6.62	3.34	13.03	0.85	3.74	0.68	0.26	0.462	0.173	0.072
7	268	8.23	3.54	17.69	1.10	8.20	1.33	-3.71	0.779	1	1
					ATM Straddle						
28	250	4.64	4.30	12.47	0.74	2.59	0.26	0.29	0.420	0.303	0.123
14	251	4.64	4.44	12.67	0.76	3.89	0.52	-0.10	0.504	1	1
7	266	4.99	5.17	21.00	1.26	8.77	0.78	-0.40	0.540	1	1
					1.01 Straddle						
28	241	3.25	5.33	13.13	0.75	2.39	0.12	0.95	0.235	0.136	0.026
14	248	3.21	6.23	14.51	0.88	5.62	0.40	1.74	0.227	0.013	0.000
7	263	2.95	7.40	24.01	1.33	7.30	0.47	2.61	0.212	0.022	0.000
					1.02 Straddle						
28	234	2.27	6.54	13.42	0.72	1.96	0.12	1.24	0.127	0.043	0.000
14	244	1.93	8.09	14.42	0.80	3.56	0.27	1.65	0.195	0.000	0.000
7	261	1.89	10.20	25.12	1.33	7.73	0.25	3.72	0.091	0.002	0.000
					0.99/1.01 Strangle						
28	241	3.35	3.41	13.10	0.75	2.41	0.09	0.92	0.243	0.143	0.030
14	248	3.34	3.53	14.61	0.90	5.65	0.34	1.84	0.217	0.031	0.000
7	263	3.38	3.69	24.84	1.44	10.91	0.44	3.44	0.161	0.022	0.001
					0.98/1.02 Strangle						
28	235	2.41	2.71	13.49	0.73	1.98	0.09	1.31	0.120	0.040	0.001
14	244	2.17	2.72	14.32	0.82	4.84	0.22	1.55	0.216	0.004	0.000
7	261	2.13	2.62	25.12	1.35	9.26	0.18	3.72	0.099	0.004	0.000

Table 4

Short Put Overpricing Results, 1990.01-2013.02

The table presents the average returns for writing put options equally weighted in each moneyness range. The number of traded put portfolios corresponds to the position becoming worthless with the index decreasing by 50% at the maturity date. There were 278 observation dates in total.

Statistic	With Tr. Costs Moneyness range			Without Tr. Costs Moneyness range			S&P 500
	0.91-0.96	0.93-0.98	0.95-1.00	0.91-0.96	0.93-0.98	0.95-1.00	
				28-day Puts			
μ	6.86	9.53	11.21	7.92	10.77	12.68	8.77
σ	12.09	14.24	17.02	12.10	14.23	17.01	16.05
Sharpe R.	0.57	0.67	0.66	0.65	0.76	0.75	0.55
min(R) – 1	-36.07	-38.65	-40.84	-35.69	-38.23	-40.39	-24.79
CAPM α	2.44	3.87	3.68	3.49	5.11	5.14	0
p-value	0.214	0.072	0.094	0.076	0.018	0.020	N/A
				14-day Puts			
μ	5.58	9.66	14.04	7.00	11.42	16.27	9.34
σ	9.57	11.74	14.56	9.45	11.61	14.44	16.56
Sharpe R.	0.58	0.82	0.96	0.74	0.98	1.13	0.56
min(R) – 1	-19.98	-22.47	-24.67	-19.45	-21.93	-24.11	-18.67
CAPM α	2.33	5.22	7.64	3.78	7.00	9.89	0
p-value	0.320	0.053	0.008	0.103	0.009	0.001	N/A
				Seven-day Puts			
μ	6.99	12.22	19.28	9.09	14.93	22.91	17.53
σ	6.81	9.79	13.87	6.74	9.71	13.79	18.48
Sharpe R.	1.03	1.25	1.39	1.35	1.54	1.66	0.95
min(R) – 1	-12.26	-15.18	-17.70	-11.73	-14.57	-17.04	-16.98
CAPM α	3.31	6.22	9.12	5.47	8.98	12.79	0
p-value	0.175	0.057	0.019	0.025	0.006	0.001	N/A

Figure 1

The figure plots annual median of proportional spreads around midpoint price for ATM ($\frac{K}{S_t}$=1) and OTM ($\frac{K}{S_t}$=0.93) put options with 28 days and seven days to maturity. Solid darker (lighter) lines correspond to 28-day ATM (OTM) options; dashed darker (lighter) lines correspond to seven-day ATM (OTM) options.