Do Option-Based Measures of Stock Mispricing Find Investment Opportunities or Market Frictions?

Martijn Cremers[a],

Ruslan Goyenko[b],

Paul Schultz[a],

and

Stephen Szaura[b]

Abstract

Researchers have proposed several option-based measures of stock mispricing. These measures are based on differences between implied and actual stock prices, differences in implied volatilities across options, and on option trading volume. In general, stocks that these measures indicate are mispriced are small and/or hard to borrow. When small and hard-to-borrow stocks are omitted, returns to shortselling are insignificant for some of the measures and greatly diminished for others. Three of the nine measures we test, however, predict positive abnormal returns for value-weighted portfolios. There are no obvious market frictions to prevent investors from earning these abnormal returns.

November, 2019.

[a]Mendoza College of Business, University of Notre Dame.
[b]Desautels Faculty of Management, McGill University.
The authors acknowledge financial support of CDI (Canadian Derivatives Institute). We have received helpful comments from Paul Gao, Rafael Zambrano, and seminar participants at the University of Notre Dame and the University at Buffalo.
Corresponding author: Paul Schultz, pschultz@nd.edu.

1. Introduction

A number of studies, including An, Ang, Bali, and Cakici (2014), Cremers and Weinbaum (2010), Hu (2014), Johnson and So (2012), Manaster and Rendleman (1982), Muravyev, Pearson, and Pollet (2018), Pan and Poteshman (2006), and Xing, Zhang, and Zhao (2010) propose option-based measures of stock mispricing. These measures are different from each other, but fall into three categories. Some use differences between implied and actual stock prices, others rely on differences in implied volatilities across different options or over time, and still other measures are based on trading volume. Recent research demonstrates that these measures predict abnormal stock returns. To date however, nobody has compared what these measures capture and when they do and do not work. In this paper, we use nine option-based measures of stock mispricing to predict stock returns. Much of the predictability comes from illiquid or hard-to-borrow stocks, but some of the measures appear to generate significant positive abnormal returns from long-only strategies.

There are two necessary conditions for options to predict stock returns. First, at least some informed investors must trade options. There are good reasons for them to do so. Informed investors with positive information can obtain far greater implicit leverage by purchasing calls than they could get by buying stock on margin. Similarly, by purchasing puts, informed investors who believe a stock is overpriced can take a bearish position that requires far less collateral than is required to short the stock directly. For informed investors, buying puts provides additional advantages over shorting stock. If the stock price increases, an investor with a short position must post additional margin or close part of his position. No additional money is required from a put holder. A short seller must borrow shares to short and it is sometimes costly or difficult to do so. If the borrowed shares are recalled and the short seller is unable to locate new shares, the short position may have to be closed prematurely. Put buyers, on the other hand, can maintain their position until the option expires.

The second condition for options to predict stock returns is that stock prices must adjust slowly to information in options. In general, economists attribute slow adjustment of prices to information to market frictions or limits of arbitrage. These include the costs of trading, particularly for illiquid securities, and the risk that prices can move in the wrong direction before finally incorporating information. There are additional important frictions that can prevent stock prices from responding quickly to negative information. Many institutional investors, like mutual funds, are restricted to long positions. They cannot short stocks. In addition, some stocks are very difficult or expensive to short. These hard-to-borrow stocks are often smaller companies. Market frictions are likely to be especially important in slowing the response of stock prices to information in options because market frictions may lead informed investors to trade options rather than the stock. For example, informed investors may choose to trade options because it is difficult to sell the underlying stock short.

We find that the stocks that option-based mispricing measures identify as mispriced are disproportionately small or hard to borrow. When we sort them into value-weighted, rather than equal-weighted portfolios, several of the measures appear to have little or no ability to find mispriced stocks. Some measures pick portfolios that generate significant negative alphas. After discarding hard-to-borrow stocks, however, the negative alphas either disappear or shrink dramatically. Option-based measures of stock mispricing, for the most part, find market frictions rather than investment opportunities.

There appear to be exceptions though. We find that three of these measures produce portfolios of *undervalued* stocks that earn positive Fama-French-Carhart four-factor alphas over the following months. Long-only quintile portfolios formed with these measures earn cumulative abnormal returns of 2.6% to 3.1% in the 12 months after portfolio formation. These results are harder to explain. It is not surprising that some informed investors with bullish information trade options. The implicit leverage of options can increase their returns. It is surprising that stock prices do not adjust quickly to the information in options. Options prices, implied volatilities, and trading volume are easy to observe. Investors do not have to borrow stock and go short to take advantage of these apparent mispricings. Institutions that are restricted to taking long positions in stocks can earn these abnormal returns. The portfolios are value-weighted, so profiting from the mispricing does not require investors to take positions in tiny stocks. Arbitrage risk does not appear to be important. Sharpe ratios for portfolios of undervalued stocks exceed the Sharpe ratios of the S&P 500 and the CRSP value-weighted market portfolio.

It would seem that since all of these measures would contain the same information about future stock returns since all are derived from options. We find though, that correlations of portfolio placements across mispricing measures are low. This suggests that combining measures may produce portfolios with larger future abnormal stock returns. This is true, but only on the short side. The larger negative abnormal returns that are earned on paper by combining measures are, however, earned by portfolios that contain very high proportions of hard-to-borrow stocks. Combining measures does not produce portfolios with larger positive abnormal returns on the long side.

For the most part, option-based measures of mispricing find market frictions. In some cases though, they appear to find investment opportunities.

The rest of this paper is organized as follows. Section 2 explains why informed investors may trade options rather than shares. Section 3 reviews option-based measures of stock mispricing and discusses how the measures are estimated in this paper. In Section 4 we estimate returns and alphas for portfolios created by sorting stocks on the basis of option-based measures of stock mispricing. Section 5 concludes.

2. Informed trading and options

Black (1975), and many subsequent papers, note that investors with information may choose to trade options rather than stock. For informed investors, trading options provides two significant advantages over trading shares. First, it is often easier and cheaper to buy put options or sell call options than it is to short-sell shares. Short-selling can be expensive, and it may be difficult to find shares to borrow. In addition, short-sellers face the risk of margin calls if the stock price increases. In those cases, buying puts or writing calls provide attractive alternatives for investors who believe that a stock is overvalued.

In addition, options provide leverage and relax the investors' borrowing constraints. When buying stock on margin, an investor cannot borrow more than 50% of the stock's cost. A basis of option pricing theory is that a call option can be replicated by borrowing money and buying shares. The implicit borrowing in an option purchase, particularly if the option is out-of-the-money, can be much greater than 50%. The implicit leverage means that for an informed investor, returns are much higher for an option position than a stock position.

The implicit leverage in call options can be seen in the Black-Scholes model. The value of a European call is

$$C = \left(S - \sum_{i=1}^{I} e^{-rt_i} D_i\right) N(d1) - e^{-rT} K N(d2), \quad (1)$$

where $d1 = \frac{\log\left(\frac{(S - \sum e^{-rt} D)}{K}\right) + (r + \sigma^2/2) * T}{\sigma\sqrt{T}}$ $and\ d2 = d1 - \sigma\sqrt{T}$, S is the stock price, $\sum_{i=1}^{I} e^{-rt_i} D$ is the present value of dividends paid over the life of the option, K is the strike price, r is the risk-free interest rate, σ is the stock volatility, T is the time to expiration, and N(.) is the cumulative normal distribution.

Note that Black-Scholes option pricing is based on replicating a call option using a portfolio of shares of stock combined with riskless borrowing. In the Black-Scholes formula, N(d1) is the number of shares in the portfolio, and $(S - \Sigma e^{-rT} D) \cdot N(d1)$ is the total value of the shares. The second term in the formula is the amount borrowed. Hence, the leverage implicit in a call option, which is the amount borrowed divided by the value of the shares, can be calculated as

$$Leverage\ = [e^{-rT} K N(d2)] / \left[\left(S - \sum_{i=1}^{I} e^{-rt_i} D_i\right) N(d1)\right]. \quad (2)$$

We demonstrate the implicit leverage in call options using LiveVol/CBOE intraday prices for all options over our sample period of 2004-2013. To calculate implicit leverages, we use the estimates of implied stock prices and implied volatilities from the analysis described in Section 2.1 below. We define in-the-money options as those with an absolute value for their delta of 0.625 to 0.875, at-the-money options as those with absolute values of deltas of 0.375 to 0.625, while out-of-the money options have absolute values of deltas in the range of 0.125 to 0.375[1].

Panel A of Table 1 shows the mean implicit leverage of in-the-money, at-the-money, and out-of-the-money calls in our sample for various times to expiration. Calls provide much more leverage than can be obtained by buying stocks on margin. For at-the-money calls with less than 30 days to expiration, the mean implicit leverage is 0.8835. That is, buying these calls is like buying shares and borrowing 88.35% of the cost of the shares. This leverage is much greater than the maximum margin of 50% available for buying shares. Put another way, an investor who buys at-the-money calls gets exposure to 1/(1-.8835) = $8.58 worth of stock for $1. The investor who purchases stock on margin gets exposure to, at most, $2 worth of stock for $1. As Panel A shows, leverage increases as options move further out of the money and as the time to expiration decreases. For example, for at-the-money options the implicit leverage decreases from 88.35% for options with less than 30 days to expiration to 83.1% for options with 30 to 179 days to expiration.[2] Even the options that are in the money and have more than 180 days to expiration do, however, have much greater implicit leverage than the 50% obtained by buying the stock on margin.

For puts, we calculate the proportion of money from the implicit short position that is invested at the riskless rate as collateral. When a stock is shorted, the short-seller has to put up 150% of the short-sale proceeds as collateral. In other words, a short-seller needs to use all of the proceeds of the short-sale for collateral and put up an additional 50% of the proceeds out-of-pocket. The Black-Scholes model for puts is given by

$$P = e^{-rT} K N(-d2) - \left(S - \sum_{i=1}^{I} e^{-rt_i} D_i\right) N(-d1). \quad (3)$$

The put is priced as a short position in N(-d1) shares and an investment of e^{-rT} K N(-d2) in the riskless security. The proportion of proceeds that the investor implicitly puts up for collateral out-of-pocket when he purchases a put is the price paid for the put divided by the ($S - \Sigma e^{-rt} D$) · N(-d1) proceeds from the short position. That is,

$$Percent\ Collateral = \frac{e^{-rT} K N(-d2) - (S - \sum_{i=1}^{I} e^{-rt_i} D_i) N(-d1)}{(S - \sum_{i=1}^{I} e^{-rt_i} D_i) N(-d1)} \quad (4)$$

[1] This is definition of moneyness is also used by Bollen and Whaley (2004), among others.
[2] Johnson and So (2012) use N(d1)S/C as a measure of leverage. Their measure can be thought of as the multiple of the stock return earned by investing in the option rather than the stock. So, if N(d1)S/C is 2, the option return is twice the share return. Our measure, on the other hand, gives the proportion of the position that is financed by borrowing. We use it because it makes for an easy comparison with margin requirements.

Panel B of Table 1 shows the implicit out-of-pocket collateral requirements for puts. For at-the-money options, the average of the implicit collateral requirement is 0.3933 if the option has more than 180 days to expiration, 0.2363 for options with 30 to 180 days to expiration and 0.1416 for options with 10 to 30 days to expiration. Accordingly, buying puts allows investors to have far lower out-of-pocket collateral requirements than the 50% minimum in a short sale of stock.

So, regardless of whether informed investors buy puts or calls, trading options rather than stock of equal value allows investors to earn greater potential returns on their investments. There are, however, additional reasons why option trading is especially attractive for informed investors with unfavorable information about a stock. If a short seller's collateral falls below a maintenance level, he or she must post additional collateral. If the stock price moves against a put buyer, he just has a lower level of collateral. In addition, short sellers have to borrow shares to sell, and it is difficult or expensive to borrow shares of some stocks. Dealers who sell puts to investors may hedge by shorting the underlying stock, but they are typically better able to sell short than most investors. An investor who is able to borrow shares bears the risk that the borrowed shares will be recalled early and he will be forced to terminate the short position.

Figlewski and Webb (1993) provide evidence that options trading reduces the effect of constraints on short selling. Using S&P 500 stocks over 1974-1983, they show that short interest is higher for stocks with options than for other stocks. They attribute this to options market makers shorting to hedge their positions.[3]

This is not to say that all informed trading should take place in the options market. Easley, O'Hara and Srinivas (1998) model trading by informed investors across options and shares. In the pooling equilibrium of their model, informed investors trade in both options and shares. More of the informed trading goes into options as depth in the options market increases and as the relative leverage of options increases. More trading takes place in shares as the depth of the stock market increases.[4]

Evidence suggests that most informed trading takes place in the stock market. Chakravarty, Gulen, and Mayhew (2004) use vector autoregressions of stock prices and implied stock prices from options at one second intervals to estimate the proportion of information impounded in prices by option and stock prices. Across 60 stocks, they find that the information share of options varies from 11.8% to 23.5%. The information share is higher for out-of-the money options than for in-the-money or at-the-money options.

[3] Battalio and Schultz (2011) show that the imposition of short-sale bans during the financial crisis led to a sharp increase in bid-ask spreads for options on banned stocks. Synthetic share prices of banned stocks became significantly lower than actual share prices suggesting that dealers who could not hedge discouraged investors from shorting synthetically.

[4] Bid-Ask spreads for options are wide. In percentage terms, as measured by quoted spreads, it is typically much more expensive to trade options than the underlying shares. Muravyev and Pearson (2019) show, however, that trades are more likely to occur at the ask price when the fair value of the option is close to the ask price, and more likely to occur at the bid price when the option's fair value is near the bid. Quoted spreads overstate trading costs.

The information share of options increases with the ratio of option volume to stock volume, and decreases with the ratio of option effective spreads to stock effective spreads. Kacperczyk and Pagnotta (2018) provide direct evidence of option trading by informed investors. They hand collect a sample of 5,058 trades in 615 firms that were part of insider trading investigations by the SEC over 1995-2015. Stocks accounted for 67% of these trades and options accounted for 32%. Implied volatilities and volume from options were abnormally high while insiders were trading.

3. Option-based measures of stock mispricing

A number of option-based measures of stock mispricing have been proposed. We are the first to compare their performance under similar conditions and to show when they do and do not succeed in predicting stock returns. We are not interested in overnight returns generated by these measures as these returns may be due to microstructure noise. Instead, we focus on monthly returns that can be earned for up to a year after these measures are estimated.

We separate option-based measures of stock mispricing into three categories. The first category is measures based on the difference between implied and actual stocks prices. These measures use an options pricing model (e.g. Black-Scholes) or an arbitrage bound to generate an implied stock price. The second category is measures based on implied volatilities. These measures use an option pricing model to generate implied volatilities and compare them across options or over time. The third category is measures based on trading volume. These measures compare bullish and bearish trading volume, or trading volume across options and the underlying stock.

3.1. Measures based on differences between implied and actual stock prices

An early paper that used implied stock prices from options to predict stock returns is Manaster and Rendleman (1982). Their data consists of daily closing prices for call options from April 26, 1973 – June 30, 1976. They omit calls on days when the present value of the dividends to be paid over the life of the option exceeds the present value of interest foregone by early exercise. This removes all call options that could rationally be exercised early from their sample. They calculate implied stock prices each day by finding implied prices and volatilities that minimize the sum of the squared differences between dividend-adjusted Black-Scholes prices and market prices of all call options. Manaster and Rendleman rank stocks by the percentage difference between implied and actual stock prices, which they label Δ, and sort stocks into Δ quintiles. On average, the difference in the returns the next day for high and low Δ quintiles is over 18 basis points.

We implement the Manaster and Rendlemann (1982) measure in the following way. We jointly estimate the implied stock price and implied volatility using the extended Black Scholes model for a European option on dividend paying stocks. For each option contract (identified as a call or put, by expiration date, and by strike price), over each 30 minute interval, we use an iterative process to solve for the values of $S_{Implied}$ and $\sigma_{Implied}$ that minimize the sum of the squared differences between option trade prices (or quote midpoints) and Black-Scholes prices. Specifically, for call options we solve

$$\min_{S_{Implied},\sigma_{Implied}} \sum_{t=1}^{T} \left(\left(S_{Implied} - \sum_{i=1}^{I} e^{-rt_i} D_i \right) N(d1) - e^{-rT} K N(d2) - C_t \right)^2, \quad (5)$$

where C_t is the observed call option trade price for option trade t from LiveVol and T is the number of option trades in 30 minute interval. $S_{Implied}$ and $\sigma_{Implied}$ are calculated for put options in an analogous manner. We require that there be at least 3 different option trade prices within a 30 minute interval in order to uniquely identify the implied stock and volatility. Otherwise the interval is discarded.[5]

We then calculate daily relative implied prices ('RIP') using the mean difference between implied prices and stock midpoints in each half hour interval. That is

$$RIP \quad = \sum_{i} \frac{(S_{Implied,i} - S_{Midpoint,i})}{S_{Midpoint,i}} / N, \quad (6)$$

where i denotes the half-hour interval, N is the number of 30-minute intervals for which implied prices can be calculated, $S_{Midoint,I}$ is the stock quoted midpoint in the end of 30 min interval, and RIP is the relative implied price measure based on estimation using option trade prices.

Our measure of the implied price difference ('IPD') of stocks, based on option trades and actual stock prices, is obtained by averaging RIP for each day across options on a stock using open interest as weights, and then averaging across all days in a month. IPD is calculated using only 30-minute intervals for which at least three option trade prices are available. Hence, it is only calculated during periods of price discovery. As such, we can think of it as the average percentage difference between option-implied stock prices and actual stock prices during periods of price discovery.

---

[5] As a starting point for the iterative process, we use the stock quote midpoint (average of the stock bid and ask) and the option implied volatility (calculated in LiveVol using the CRR tree method adjusted for dividends) of the last trade of the prior 30 minute interval. When solving for $S_{Implied}$ and $\sigma_{Implied}$: we perform the iteration over the log starting values to avoid the situation where the implied stock and implied volatility become negative and we impose the condition in the joint estimation of : $S_{Implied} - \sum_{i=1}^{I} e^{-rt_i} D_i > 0$ since in the expression $d1$ the term $\log\left(\frac{(S_{Implied} - \sum_{i=1}^{I} e^{-rt_i} D_i)}{K}\right)$ results in an error when $S_{Implied} - \sum_{i=1}^{I} e^{-rt_i} D_i < 0$.

We also calculate RIP and IPD using option bid-ask midpoints at the time of trades rather than option trade prices. IPD calculated from bid-ask midpoints is highly correlated with IPD estimated from trades, but IPD estimated from trade prices is a somewhat stronger predictor of stock prices. Hence we focus on that measure in the empirical work to follow.

IPD is based on Manaster and Rendleman (1982), but there are some differences. First, we use option trades for an entire month to estimate IPD. We are interested in prediction of long-term stock returns. This requires that information must be incorporated slowly and hence it is appropriate to use a longer period to estimate IPD. Second, we use intraday trades. This allows us to match option trades with simultaneous stock quotes. It also increases the number of observations used in the estimation. Finally, we use puts as well as calls to estimate implied stock prices.[6]

In calculating IPD, we do not account for early exercise. It is difficult to simultaneously solve for implied volatility, implied stock price, and the early exercise boundary. In addition, IPD is calculated almost entirely from actively traded options. These tend to be at-the-money or out-of-the-money options that are unlikely to be exercised early. When IPD is estimated using only call options on stocks that do not pay dividends, results are similar to those presented here. As we will see, IPD works very well as a predictor of stock returns. It is possible that it would work even better if early exercise is incorporated in its estimation.

Muravyev, Pearson, and Pollet (2018) derive a related measure of mispricing. They use a non-linear transformation of put-call parity violations to estimate implied stock borrowing fees that short-sellers would expect to pay. This is a significant advantage of their measure – it is based on an arbitrage bound rather than a model. They demonstrate that their measure of implied fees predicts future changes in indicative stock borrowing costs. Using data from July 2006 through August 2015, they calculate the median implied borrowing fee for each stock each day. Implied borrowing fees are a highly significant predictor of returns for the next week and for the following month. When they sort stocks into deciles by implied borrowing fees, the difference in four-factor alphas between high and low deciles over the next month is a highly significant 75 basis points. Muravyev, Pearson, and Pollet do not claim to estimate implied stock prices. Nevertheless, a put-call parity violation is observationally equivalent to a difference between implied and actual stock prices. There are many potential reasons why implied and actual stock prices can differ, but the implied borrowing fee measure assumes that differences between implied and actual stock prices occur because of short selling costs.

[6]Muravyev, Pearson, and Broussard (2013) use a similar technique. They predict returns for 39 stocks using differences between implied and actual stock prices. Their implied bid and ask prices are calculated from put-call parity.

In the empirical work to follow, we estimate implied lending fees as in Muravyev, Pearson, and Pollet (2018). We use pairs of puts and calls with the same strike price and time to expiration and attribute violations of put-call parity to borrowing fees. The estimated borrowing fee for a put-call pair is

$$h_Q^{imp} = \frac{1}{\delta}\left(1 - \left(1 - \frac{S_t - C_t + P_t - PV(D) - PV(K)}{S_t}\right)^{1/k}\right) \quad (7)$$

where h_Q^{imp} is the implied borrowing fee, δ is 1/(1+r), r is the daily discount factor, S_t is the stock price at time t, C_t is the call price at time t, P_t is the put price at time t, PV(D) is the present value of the underlying stocks' dividends over the life of the options, PV(K) is the present value of the strike price and k is the time to expiration.

3.2. Measures based on option implied volatilities

If the Black-Scholes model is correct, implied volatilities from different options on a stock with the same time to expiration should be the same. Differences in implied volatilities across options indicate that some options have high prices relative to others. Bollen and Whaley (2004) provide evidence that differences in implied volatilities across options and time reflect differences in demand for the options by investors. Information about investor demand for various types of options as reflected in implied volatilities may be useful for predicting stock returns.

Cremers and Weinbaum (2010) show that differences between implied volatilities of calls and implied volatilities of puts predict stock returns. Using all pairs of calls and puts on a stock with the same strike price and expiration date, and weighting each pair by its open interest, they calculate weighted average differences between call and put implied volatilities. A higher (lower) implied volatility for calls than puts means that the call prices are high (low) relative to the put prices. They divide stocks into five quintiles based on these differences and calculate abnormal returns over the next week and the next four weeks for these portfolios. Portfolios with call implied volatilities that exceed put implied volatilities earn positive abnormal returns while those with larger put implied volatilities earn negative abnormal returns. A strategy of going long the portfolio with the greatest difference between call and put volatilities and short the portfolio with the smallest difference produces four factor alphas of 99 basis points over the following four weeks. Cremers and Weinbaum show further that the predictive power of option prices increases as options become more liquid or underlying shares become less liquid.

In our empirical work, CW is the difference between call and put implied volatilities as in Cremers and Weinbaum (2012). We calculate CW daily for pairs of puts and calls with the same strike price and expiration date. A daily weighted average difference is calculated across option pairs using the open interest as weights. That is, for day t,

$$CW_t = \sum_i w_{i,t}\left(IV_{i,t}^{Call} - IV_{i,t}^{Put}\right), \qquad (8)$$

where i is the expiration date and strike price combination, the weight $w_{i,t}$ is the average of the put and call open interest, IV^{Call} is the implied volatility of the call and IV^{Put} is the implied volatility of the put. In calculating daily averages, option pairs are omitted if the implied volatility, option delta, open interest or option trade volume are missing, if the best bid or ask quotes are less than or equal to zero or if the ask quote is less than or equal to the bid. We omit options with absolute values of delta greater than 0.98 or less than 0.02. The average daily CW is averaged across days of the month weighting each day equally.

Xing, Zhang, and Zhao (2010) use skewness, defined as the difference between the implied volatility of out-of-the-money puts and the implied volatility of at-the-money calls, to predict future stock returns. Out-of-the-money puts maximize leverage for investors with negative news or bearish opinions about a stock. Strong demand for out-of-the-money puts will push up their prices and thus their implied volatilities. At-the-money calls are typically the most liquid options, hence subtracting the implied volatility of at-the-money-calls from the implied volatility of out-of-the-money puts provides a measure of the excess demand for puts. Using closing prices from 1996 – 2005, Xing, Zhang, and Zhao calculate weekly skewness for individual stocks by averaging daily skewness. They sort stocks into quintiles based on skewness and show that stocks with high skewness (large implied volatilities for out-of-the-money puts) underperform stocks with low skewness (small implied volatilities for out-of-the-money puts) by 15 to 20 basis points over the next week. Stocks with low skewness continue to outperform stocks with high skewness for up to six months after the portfolio formation.

An implicit assumption in the skewness measure is that informed trading of options takes place mainly by investors with negative information. This may be true if options are a way to get around short-sale constraints. Other measures based on option volume also assume that informed trading of options comes mostly from bearish investors.

We estimate skewness as the difference between implied volatilities of puts with a delta of -0.2, and the average implied volatility from put and call contracts with an absolute value of delta of 0.5. Implied volatilities are obtained from the OptionMetrics volatility surface for options with 30 days to maturity. We calculate skewness daily and average daily values to compute a skewness measure for each month.

An, Ang, Bali, and Cakici (2014) examine the power of changes in implied volatilities to forecast stock returns. Implied volatilities are obtained from the daily implied volatility surface calculated by OptionMetrics. Their empirical analysis uses end-of-month call and put implied volatilities for options with a delta of 0.5 and 30 days to maturity. An et al. sort stocks into decile portfolios each month based on the change in the stock's call and put implied volatilities. Larger increases in call volatilities are associated with larger stock returns the next month while larger increases in put volatilities are associated with lower stock returns in the following month. The difference in returns between the portfolio with the largest (typically positive) change in implied call volatility and the portfolio with the smallest (typically negative) change in implied volatility is about 1% over the next month. Differences in the next months' abnormal returns, calculated with either the CAPM or the Fama-French three factor model, are also about 1%. Differences in returns and abnormal returns across portfolios of stock with the largest and smallest changes in put implied volatilities are about 0.5%.

We replicate the An, Ang, Bali, and Cakici (2014) by calculating ΔCVOL, the monthly change in implied volatilities of calls and ΔPVOL, the month change in implied volatilities of puts. The data are from the OptionMetrics volatility surface. We remove observations with missing implied volatilities and deltas. Only at-the-money series (abs(delta)=0.5) with 30 days to maturity are retained. We use the last available daily observation of the month for each call/put for each stock to compute the monthly changes.

3.3. Measures based on option volume and order flow

Johnson and So (2012) observe that, because of short-sale restrictions, investors with negative information are particularly likely to choose to trade options rather than shares. They propose that O/S, the natural logarithm of the ratio of options volume to stock volume, may contain information about future stock returns. A high value of O/S is likely to reflect a large volume of trading by pessimistic investors who trade options rather than shares because of short-sale restrictions. Using data from 1996 – 2010, they calculate O/S using weekly volume shares of put and call options that expire between five and 35 days after the trade. They form decile portfolios based on O/S ratios and show that the four-factor alpha of the lowest O/S decile portfolio is about 34 basis points greater than the alpha of the highest decile portfolio for the week following portfolio formation.

Ge, Lin, and Pearson (2016) confirm that high O/S ratios predict negative stock returns, but also provide evidence that implicit leverage, not short-sale restrictions, is behind the measure's power to predict stock returns. They break down volume for puts and calls into buy volume and sell volume, and into trades that open and close positions. Both bullish and bearish volume predict stock returns with the strongest predictions coming from volume that opens call positions. Ge, Lin, and Pearson state that high values of O/S are associated with negative future returns because "more components of options volume negatively predict returns than positively predict returns, due to the fact that trading volume stemming from the unwinding of bought call positions negatively predicts returns."

We estimate the O/S measure used in Johnson and So (2012), and Ge, Lin and Pearson (2016) as the natural logarithm of the option to stock volume ratio. Unlike Johnson and So, who use just short-term options, we use the total option volume across all strikes and maturities. We calculate O/S monthly. We measure stock volume in round lots of 100 to make it comparable to option contracts on 100 shares.

Pan and Poteshman (2006) show that the daily ratio of the number of put contracts purchased to the sum of put and call contracts provides information on stock mispricing. A large ratio, reflecting greater public purchases of puts than calls, implies negative private information while a small ratio, reflecting greater public purchases of calls than puts, implies that traders have bullish private information. Slope coefficient estimates obtained by regressing the next-day four-factor adjusted stock return on the ratio indicate that buying stocks with all volume coming from buys of calls and selling stocks with all volume coming from put buys yields a highly significant average return of over 50 basis points over the next day. Larger excess returns are produced when they use options that are out-of-the-money or close to expiration as these options provide more leverage. Pan and Poteshman note that their results are not incompatible with market efficiency. In their tests, returns are predicted using information that is not available to the public. Investors are not able to observe whether option trades, and thus option volume, is buyer initiated.

We denote the put-to-call volume ratio as calculated by Pan and Poteshman (2006) as PP and calculate it this way

$$PP = \frac{\sum Open\ Buy\ Put}{\sum Open\ Buy\ Put + \sum Open\ Buy\ Call}, \qquad (9)$$

where Open Buy Put is the volume from purchases of puts that open put positions for customers while Open Buy Call is the volume from purchases that open call positions for customers. Open Buy and Sell trading volumes are obtained from the CBOE/ISE exchanges. We calculate PP daily and average the daily measure over the month.

Hu (2014) calculates the Options Order Imbalance (OOI) daily by summing the product of the volume for each option trade times the option trade's delta. If most of the volume occurs in option trades with negative deltas (put purchases or call sales) OOI will be negative. If most volume is from positive alpha option trades (call purchases or put sales) OOI will be positive. Options order imbalance predicts stock returns the next day even after adjusting for order imbalances in the underlying stock. The return associated with options order imbalance does not appear to be reversed in succeeding days. Hu observes that options order flow contains significant information about stock values. We compute OOI as the difference between the synthetic positive and negative exposure to the underlying stock using the signed CBOE/ISE option volume weighted by the absolute value of the option's delta and scaled by total option volume. OOI is calculated daily, averaged monthly, and is used to predict stock returns in future months.

4. Predicting stock returns with option-based mispricing measures

4.1. Data

In the empirical work that follows we use two sources of options data to estimate option-based measures of stock mispricing. CBOE/LiveVol provides intraday option trades and quotes for 2004-2013. We apply the following standard microstructure data filters to our option trades data. We remove option trades that occurred before 9:30 am or after 4:00 pm. We discard cancelled trades, trades in which the option trade price is greater than twice the contemporaneous option quote midpoint, and trades with missing prices or missing bid or ask quotes. Option trades are also deleted if contemporaneous option quote midpoints are less than ten cents, the options have zero trade volume, or have ten or fewer days to maturity. For inclusion, all option best bid and best ask quotes must satisfy the relationship 0 < Best Bid < Best Ask < 5·Best Bid. Intraday data from CBOE/LiveVol is used to estimate IPD. Signed CBOE/ISE volume data are used to estimate PP, and OOI. Our second source of options data is OptionMetrics. OptionMetrics provides daily summary statistics for individual options. It also estimates an end-of-day implied volatility surface. We use data from OptionMetrics to estimate ΔCVOL, ΔPVOL, skewness, implicit borrowing fees, CW, and O/S.

Panel A of Table 2 provides summary statistics on trading volume in the CBOE/LiveVol data. The median number of contracts with 10 to 30 days to expiration that trade in one month is 226. That is a daily average of 10 contracts for 100 shares each. The distribution of trading volume is right-skewed with some options trading a lot and others very little. Options with greater times to maturity usually have lower volume, but still trade actively. For options with more than 90 days to expiration, the mean number of contracts traded per month is 288 and the median is 142. Some measures, like skewness, are estimated from heavily traded short-term options. Others, like IPD are estimated from several different options on the same stock. Options on the 500 largest stocks, which are especially important in calculating returns of value-weighted portfolios, trade more frequently than options on other stocks.

Panel B of Table 2 reports summary statistics for option-based measures of stock mispricing. Measures like IPD, CW, or OOI are typically small on average, as we would expect them to be. There are outliers in IPD, which could occur if the stock quote midpoint was misestimated. Likewise, O/S has outliers when stock volume is very low. We discard obvious errors, but in addition, our comparisons of returns and alphas across quintile portfolios mitigates the influence of outliers.

In this paper we show that stocks that are identified as overpriced by option-based measures are often hard to borrow to short. We use indicative fee data from Markit to identify hard-to-borrow stocks. This indicative fee reflects buy side end-users demand. Panel C of Table 2 summarizes the distribution of indicative fees by year for the 2004-2013 sample period. The median fee varies from 33.8 basis points per year in 2009 to 48.2 basis points in 2004. In each year, the difference between the 1st percentile and the median indicative fee is small, typically 5-7 basis points. We define hard-to-borrow stocks as those with indicative fees that are in the top 20%. The 80th percentile indicative fee is usually two to four times as large as the median fee. For example, in 2013 the median fee is 39.2 basis points while the 80th percentile fee is 1.72%. The 99th percentile of indicative fees are much higher than the median fees, and exceed 40% in 2011 and 2012.

4.2 Returns and alphas of portfolios formed on options-based measures

The nine option-based measures of mispricing used here have been shown to predict abnormal stock returns. This could be because informed investors trade options and the stock market incorporates the information from options slowly. In this case, it should be possible to earn abnormal returns in practice with the aid of these measures. On the other hand, it may be that informed traders trade options in part because of market frictions in the market for the underlying stock, and that these frictions prevent investors from profiting from mispricings in practice. In this section, we attempt to minimize the impact of market frictions and see if option-based measures of mispricing still yield abnormal returns.

We test whether abnormal returns can be earned using value-weighted portfolios sorted on option-based measures of mispricing. Fama and French (2008) caution against using long-short returns from equal-weighted portfolios to examine anomalies. They note that the cross-sectional dispersion of anomaly variables is largest among very small firms. Hence, small, illiquid stocks that are expensive to trade dominate long-short returns from equal-weighted portfolios. Fama and French observe that a similar problem arises stock returns are regressed on anomaly variables. The extremes of the explanatory variables are likely to be small and illiquid firms. We would add that small stocks are also more likely to be difficult to borrow and sell short. Strategies that use value-weighted portfolios are more likely to be implementable in practice.

We are also concerned that the profiting from option-based measures of mispricing requires investors to short stocks that are costly or difficult to short in practice. The profitability of many anomalies that seem to promise abnormal returns depends on short-selling hard-to-borrow stocks. Stambaugh, Yu and Yuan (2012) construct value-weighted decile portfolios of stocks sorted on 11 anomaly variables over August 1965 through January 2008. Long-short portfolios produce statistically significant three-factor abnormal returns for each anomaly variable. For ten of the 11, the absolute value of the abnormal returns is larger on the short leg than long leg. The differences in abnormal returns are usually large. Stambaugh, Yu, and Yuan show further that the poor (good) performance of overpriced (underpriced) stocks is especially strong for stocks with high idiosyncratic volatilities and hence greater arbitrage risk.

Jacobs (2015) examines the returns to 100 anomalies over August 1965 through January 2011. These anomalies are grouped into 19 meta anomalies like earnings surprise anomalies and long-term reversal anomalies. Jacobs notes (page 80) that "most meta anomaly returns are effectively driven by the short-leg."

Using value-weighted portfolios reduces but does not eliminate the influence of hard-to-borrow stocks on the returns from strategies based on of options. We also examine the returns to option-based measures of mispricing after eliminating hard-to-borrow stocks. Finally, we examine the returns to long-only strategies that use value-weighted portfolios. The returns to these strategies are not diminished by the high trading costs of small stocks or by the costs of borrowing shares for short-selling.

Each month, we sort stocks into quintile portfolios by each of the following option-based mispricing measures: IPD, Implied Lending Fees, CW, Skewness, ΔCVOL, ΔPVOL, OOI, PP, and O/S. Each month, we calculate the average market capitalization of stocks in each quintile portfolio for each option-based mispricing measure. We then calculate grand averages across months. These average sizes, in billions of dollars are shown in Panel A of Table 3.

For all option-based measures except Pan-Poteshman, both the low and high quintile portfolios tend to have smaller firms than the middle portfolios. For example, the average capitalization of low IPD stocks is just $2.75 billion, while the average size of third quintile IPD stocks is $13.82 billion. Similarly, the mean size of the stocks in the high implied fee portfolio is only $1.7 billion, while the mean capitalization of stocks in the third implied fee quintile is $10.16 billion. Likewise, the mean firm size for stocks in the high skewness portfolio is just $2.65 billion while the mean size is $8.36 billion for third skewness portfolio and $13.58 billion for the second lowest skewness portfolio. Profiting from these option-based measures of stock mispricing involves trading small firms. Small stocks are illiquid and expensive to trade. It is difficult to acquire a significant number of shares without moving the price. The concentration of small stocks in extreme portfolios is an even bigger problem if decile portfolios are used.

Not only are small firm stocks more expensive to trade than large firm stocks, they are also more likely to be difficult to borrow for short sales. We obtain indicative lending stock lending fees for all stocks for each month in our sample period from Markit. We designate a stock as hard to borrow if the indicative fee for that stock is among the highest 20% of all stocks, not just stocks with options, during that month. Optionable stocks are larger and more liquid than those without options, so we would expect fewer than 20% of stocks with options to be hard-to-borrow. For each quintile portfolio of each mispricing measure, we calculate the proportion of stocks in the portfolio that are hard to borrow each month, and average the proportion over the months of our sample period. Panel B of Table 3 reports these averages.

For several measures, the quintile portfolio containing overvalued stocks is overweighted in stocks that are hard to borrow. The low IPD portfolio contains stocks in which the implied stock price is low relative to the actual stock price. On average, 33.88% of the stocks in that portfolio are hard to borrow. In comparison, only 10.74% of the high IPD stocks are hard to borrow. Similarly, 30.72% of the portfolio with high implied lending fees is composed of hard to borrow stocks. Only 5.56% of the stocks in the low borrowing fee portfolio are hard-to-borrow. For the low CW portfolio, which consists of stocks with high implied volatilities from puts relative to the implied volatilities from calls, 37.07% of stocks are hard to borrow. In contrast, only 12.34% of the stocks in the high CW portfolio are hard to borrow. The proportion of stocks that are hard to borrow increases monotonically from 6.69% in the low O/S portfolio to 21.13% in the high O/S portfolios.

Table 3 demonstrates that option-based measures of stock mispricing pick out small and hard-to-borrow stocks. That is, they find stocks with market frictions that may prevent investors from profiting from mispricing. This may be because informed investors trade the options because frictions like high borrowing costs make it difficult to trade shares. Or, it may be that these stocks adjust more slowly to information in options.

In the appendix, we present returns and four factor alphas for equal-weighted quintile portfolios formed using each of the option-based measures of mispricing. These measures appear to produce large long-short returns, but the significant mispricing appears to be almost entirely on the short-side. As Table 3 shows, the quintile portfolios that these measures indicate are overpriced are overweighted with small and hard-to-borrow stocks. Option-based measures of mispricing are very good at finding market frictions.

We next see if option-based measures of stock mispricing can be used to generate abnormal returns after minimizing the influence of small, hard-to-borrow stocks. We calculate returns and four-factor alphas for each of the three months following portfolio formation for value-weighted quintile portfolios. Value-weighting minimizes the contribution of small, illiquid stocks to the portfolio returns. Because hard-to-borrow stocks are often small, value-weighting also minimizes the impact on returns of stocks that are difficult to short. As we will see, some option-based measures of mispricing that work with equal-weighted portfolios have no ability to predict returns of value-weighted portfolios.

Table 4 presents time-series averages of monthly returns and Fama-French-Carhart four factor alphas for portfolios. Panel A reports results for measures based on differences between implied and actual stock prices. Long-short portfolios formed both on IPD and implied borrowing fees produce significant abnormal returns in the three months following portfolio formation. For IPD, for example, the long-short portfolio produces alphas of 63.64 basis points, 79.36 basis points, and 83.92 basis points in the three months following portfolio formation. Both measures produce significant abnormal returns on the short side. For the high implied borrowing fee portfolio, alphas are -38.73 basis points, -30.61 basis points, and

-38.29 basis points in the three months following portfolio formation. More interesting is that the high IPD portfolio, that is the one in which implied prices are highest relative to actual prices, earns positive abnormal returns of 26, 39, and 43 basis points over months t+1 through t+3. Each of these alphas is significantly different from zero at the 1% level. Short sales are not needed to earn the abnormal returns of the high IPD portfolios. Because these portfolios are value-weighted, trading costs and price impact should be minimal.

Panel B presents results for value-weighted quintile portfolios formed using measures based on implied volatility. In general, these results are weak. Portfolios based on CW, for example, do not provide significant long-short returns or significant long or short-side abnormal returns. In the appendix, where portfolios are equal-weighted rather than value-weighted, CW, and other measures produce large and significant returns for short portfolios. Nevertheless, in value-weighted portfolios, as shown in Panel B, skewness provides significant long-short returns in months two and three after portfolio formation. It also provides significant positive long-side alphas in month t+3, and, as we will show, in later months as well. ΔPVOL fares best of the measures, and provides significant long-short abnormal returns as well as significant negative abnormal returns for short portfolios.

Panel C reports returns and four-factor alphas for value-weighted portfolios formed using measures based on option volume. Sorts based on PP do not produce any statistically significant four-factor alphas. Sorts on OOI yield a statistically significant negative four-factor alpha for the second month and the second month only. On the other hand, results for value-weighted portfolios based on O/S are quite strong. Alphas are statistically significant for the short side (high options to stock volume) each month. In addition, sorts on O/S, like IPD, produce statistically significant alphas each month on the long side. Alphas for the low O/S portfolio are 25.60 basis points, 26.75 basis points, and 26.88 basis points for the three months after portfolio formation.

The results in Table 4 show that at least three option-based measures seem to predict positive alphas for value-weighted portfolios. IPD and O/S based portfolios produce positive alphas in each of the three months after portfolio formation. The low skewness portfolio has positive alphas in each of the three months following formation, but it is only in the third month that the alpha is significantly different from zero. We will show, however, that the low skewness portfolio continues to earn abnormal returns in succeeding months. These three measures then generate trading strategies that produce significant alphas but do not involve shorting stocks and do not rely on trading small firms. Cumulative positive alphas over the three months following portfolio formation are significant but modest. For high IPD portfolios they are just over 1% and for low O/S portfolios they are about 80 basis points.

Portfolios formed using four of the option-based measures of mispricing, IPD, implied fees, ΔPVOL, and O/S, have negative and statistically significant abnormal returns after portfolio formation. Using value-weighted portfolios as we do in Table 4 reduces the impact of short-sale constraints, but they may still be a factor. To see if the negative abnormal returns can be earned by shorting stocks, each month we sort stocks into value-weighted quintile portfolios based on each of the nine option-based measures of mispricing after taking out all stocks that are hard-to-borrow that month. The remaining stocks all have indicative borrowing fees below the 80th percentile that month. We then calculate returns and four-factor alphas for each of these portfolios over each of the next three months. We report the alphas in Table 5 alongside the alphas from Table 4 for portfolios that include the hard-to-borrow stocks. To save space, we report the alphas for just the high and low portfolios and the long-short portfolio.

Panel A provides results for portfolios formed using measures based on the difference between implied and actual stock prices. When we exclude hard-to-borrow stocks, the alphas of the high implied fee portfolios shrink dramatically. For example, the alpha for the high implied fee portfolio for month t+1 is -0.3873 with a t-statistic of -2.65 when all stocks are included, but just -0.0499 with a t-statistic of -0.33 when we exclude hard-to-borrow stocks. The alpha for month t+2 for portfolios with high implied fees is -0.3061 with a t-statistic of -2.27 when all stocks are included, but 0.0173 with a t-statistic of 0.13 when we exclude hard-to-borrow stocks. The implied fee variable is supposed to identify hard-to-borrow stocks, so it is not surprising that it loses power when we omit hard-to-borrow stocks. Results for IPD are also weaker when we omit hard-to-borrow stocks. When all stocks are included, the alpha of the low IPD portfolio is -0.3810 with a t-statistic of -2.33. When we exclude hard-to-borrow stocks, the alpha falls to -0.0597 with a t-statistic of -0.33.

Panels B and C of Table 5 present results for measures based on implied volatilities and on option volume. In general, regardless of the measure used, alphas and t-statistics fall for quintile portfolios of overvalued stocks when we exclude hard-to-borrow stocks. For O/S in particular, alphas move much closer to zero when hard-to-borrow stocks are omitted. For the high O/S portfolio with all stocks included, alphas are -0.1854 with a t-statistic of -4.37, -0.2005 with a t-statistic of -2.41, and -0.2311 with a t-statistic of -3.94 for the three months after portfolio formation. When the hard-to-borrow stocks are omitted, the alphas shrink to -0.0662 with a t-statistic of -1.55 for the first month, -0.0714 with a t-statistic of -1.81 for the second month, and -0.1128 with a t-statistic of -2.37 for the third month. Most of the poor performance of high O/S stocks is explained by the fact that a high O/S measure is an indication that the stock is hard to borrow.

To summarize, when stocks are value-weighted, some option-based measures of mispricing are unable to produce portfolios with significant negative alphas. Using value-weighed portfolios but dropping hard-to-borrow stocks eliminates abnormal returns to short-selling based on IPD or implied fees. There still appears to be some returns to shorting based on ΔPVOL and O/S, but returns are greatly diminished when hard-to-borrow stocks are eliminated.

Results in Table 4 showed that three measures, IPD, skewness, and O/S, produced portfolios that earned positive and significant abnormal returns in the three months after portfolio formation. These abnormal returns are particularly perplexing. The portfolios are value-weighted, so tiny illiquid stocks are not driving the results. A long only portfolio strategy appears to earn these abnormal returns, so no short-selling is required. The returns over the first three months are, however, relatively small. This raises the question of whether these portfolios continue to earn positive abnormal returns after the three months. In Table 6, we report alphas for high and low IPD, skewness, and O/S portfolios for each of the 12 months following portfolio formation.

Table 6 reports four-factor alphas for the 12 months after portfolio formation for portfolios based on IPD, skewness and O/S. In each case, high and low quintile alphas are reported along with the alphas of the long-short portfolio. What is of particular interest is that these measures appear to produce portfolios with positive and significant alphas for several months after portfolio formation. The first column of Table 6 shows that the high IPD portfolio earns positive and statistically significant abnormal returns for each month from t+1 through t+6. They continue to earn mostly positive but mostly insignificant returns for months t+7 through t+12. This suggests that positive alphas can be earned for several months after portfolio formation through a long-only strategy. Long only portfolios provide cumulative alphas of 3.10% over months t+1 through t+12. The low skewness portfolio earns positive alphas for months t+1 through t+11, and the alphas are statistically significant for months t+3 through t+6. The cumulative return for the twelve months, obtained by summing the individual month alphas is 2.67% for the low skewness portfolio. Low O/S portfolios have positive four-factor alphas in each of the 12 months following portfolio formation. They are statistically significant for months t+1 through t+9. After 12 months, the cumulative alpha for low the O/S portfolio is 2.64%.

These positive alphas appear to be abnormal returns that investors could earn. There are no short selling costs or constraints to with which to contend. Institutional investors who are constrained to long-only strategies should be able to earn these returns. The portfolios are value-weighted, so a strategy to exploit these alphas does not require buying tiny stocks.

4.3. Arbitrage Risk

Option-based measures of mispricing may allow investors to earn abnormal returns, but it may be risky to earn those abnormal returns. Investing in stocks that are indicated to be underpriced by IPD, O/S, or skewness may lead investors to hold undiversified portfolios for long periods of time. Each of the quintile portfolios holds a large number of stocks, but it is possible that portfolios are overweighted in some industries or in stocks with common characteristics.

A way to see if exploiting these measures leads investors to take extra risks is to compare the Sharpe ratios of these portfolios of stocks that are identified as underpriced with the Sharpe ratio of the market portfolio. The Sharpe ratio measures the return to total risk ratio for an investor's holdings. We estimate it for the high IPD portfolio by calculating the excess return of the portfolio (return minus the riskfree rate) in the month after formation for each month over 2004-2013. The Sharpe ratio for IPD for the first month after portfolio formation is the ratio of the time-series average of the first month excess returns to the standard deviation of the first month excess returns. We also calculate Sharpe rations for the high IPD portfolio for each of months 2 through 12 after portfolio formation. Analogous Sharpe ratios are calculated for the low skewness and low O/S portfolios. Table 7 reports the Sharpe ratios.

For IPD, the Sharpe ratio for the month after portfolio formation is 0.18, and it exceeds 0.2 for months t+2 through t+6.[7] It is somewhat lower over the next six months but exceeds 0.15 in all but one month. For comparison, the Sharpe ratio for the S&P 500 was 0.1219 over the sample period, while the Sharpe ratio for the CRSP value-weighted index was 0.1236. An investor who invested only in the in the high IPD portfolio had a larger ratio of return to risk than an investor who held the market portfolio.

The last two columns of Table 7 provide Sharpe ratios for the low O/S and low skewness portfolios. These Sharpe ratios are a little smaller than the Sharpe ratios for IPD, but still much higher than the Sharpe ratio of the CRSP value-weighted index. It appears that the mispricing indicated by O/S and skewness could also be exploited without taking extra risk.

4.4. Combining Measures

We have used several option-based measures of stock mispricing to form portfolios that produce positive or negative abnormal returns in the subsequent months. Even though all of the measures are derived from options, it is not clear whether the measures are based on the same information. If different option-based measures contain different information, they will produce stock sortings that have low correlations with each other. If this is true, combinations of option-based measures of stock mispricing can be used to produce larger abnormal returns. We are particularly interested in whether we can combine measures to produce portfolios that earn larger positive abnormal returns for long positions.

Table 8 reports correlations of quintile sortings of stocks produced by the option-based measures. There are some high correlations. Quintile portfolio placements by ΔCVOL and ΔPVOL have a correlation of 0.570, while the correlation between placements by CW and implied lending fees is -0.500. For the most part though, correlations are low. For example, the correlation between IPD and O/S is -0.057. The low

[7] We do not claim that these ratios are independent.

absolute values of correlations suggest that double sorts on two measures may produce portfolios that will earn larger abnormal returns.

There are 36 possible pairs of our nine option-based measures. We select three pairs of measures to use in double sorts: IPD and O/S, IPD and skewness, and implied lending fees and skewness. Each of these measures does a good job of identifying mispricings by itself, and the correlations of quintile portfolio placements between pairs of measures are low. For each pair of measures, we first sort stocks into quintiles by the first measure (IPD, IPD, and implied fees) and then sort each quintile into five portfolios by the second measure (O/S, skewness, and skewness). Each double sort produce 25 portfolios with equal numbers of stocks. We then calculate the value-weighted return and Fama-French-Carhart four-factor abnormal return for each portfolio for the month after portfolio formation. Table 9 reports the abnormal returns for these double-sorted portfolios.

Value-weighted portfolios formed from stocks with two bearish option measures, low IPD and high O/S, low IPD and high skewness, or high implied fees and high skewness, have large negative alphas. For example, the value-weighted portfolio formed from the combination of low IPD and high O/S earns a average abnormal return of -96.31 basis points in the month after portfolio formation. This is far larger in absolute value than the abnormal return earned by the low quintile IPD portfolio (-38.10 basis points) or the high quintile O/S portfolio (-18.54 basis points). Likewise, the portfolio formed from the combination of high skewness and high implied fee stocks earns an abnormal return of -65.80 basis points in the month after portfolio formation, which is larger than the abnormal return earned by the implied fee quintile portfolio or the high skewness portfolio. Double sorts can produce portfolios that underperform by more than portfolios produced by sorting on one measure – at least before shorting costs.

The double-sorts do not, however, seem to produce portfolios with larger positive alphas in the month after portfolio formation. Table 9 shows that the alpha for the portfolio of low O/S and high IPD stocks is only 22 basis points. The alpha for the portfolio of stocks with low skewness and low implied fees is positive but less than one basis point. Double sorts do not improve on any positive alphas earned by value-weighted portfolios formed using just one measure.

Table 10 reports the proportion of stocks that are hard-to-borrow in each portfolio produced by the double sorts in Table 9. As might be expected, the double-sort portfolios with the largest negative alphas contain a large fraction of stocks that are hard-to-borrow. The portfolio formed from stocks in the low IPD high O/S quintiles earns an alpha of -96.31 basis points, but Table 10 shows that 65.3% of the stocks in that portfolio are hard-to-borrow. Similarly, the high implied fee high skewness portfolio earns an abnormal return of -65.80 basis points in the month after portfolio formation, but 31% of the stocks in that portfolio are hard-to-borrow.

5. Conclusions

Several recent empirical papers show that information in options can predict stock returns. On the one hand, it is not surprising that informed investors would choose to trade options rather than shares. Options provide greater leverage than can be obtained with shares and can be used to make bearish bets when it is difficult to sell short. On the other hand, it is somewhat surprising that stock prices can lag options by several months. Information from options is readily available and, in the absence of market frictions, should be incorporated in stock prices quickly.

In this paper, we examine the profitability of stock trading using three categories of option-based measures of stock mispricing: measures based on stock prices implied by options, measures based on implied volatilities, and measures based on option trading volume. When we minimize the influence of tiny stocks is by using value-weighted portfolios, some of these measures appear to have no predictive ability. Some identify portfolios of overvalued stocks that earn negative alphas in the months after portfolio formation, but most of this predictive ability disappears when we exclude hard-to-borrow stocks from the portfolios. Option-based measures of stock mispricing do find stocks that adjust slowly to information because of market frictions.

Three option-based measures of mispricing, IPD, the difference between implied and actual stock prices, O/S, the logarithm of the ratio of option volume to stock volume, and skewness, the difference between the implied volatilities of out-of-the-money puts and at-the-money calls, identify undervalued stocks that produce positive abnormal returns in value-weighted portfolios. These appear to be returns that investors can actually earn. The portfolios are value-weighted, so the strategies do not involve trading tiny, illiquid stocks. In addition, short selling is not required. When IPD is used to identify undervalued stocks, cumulative four-factor alphas for value-weighted portfolios are about 3.1% after 12 months. When O/S is used to find underpriced stocks, four-factor alphas cumulate to about 2.6% in one year. The low skewness portfolio has a four-factor alpha of 2.7% for 12 months. Arbitrage risk doesn't appear to be a significant impediment to exploiting the misvaluation implied by these option-based measures. Sharpe measures for long portfolios formed on each of these measures exceed the Sharpe ratio of the market portfolio over the same time period.

The portfolio placements of stocks by different option-based measures have relatively low correlations. This suggests that double sorts on different option-based measures of mispricing may produce larger abnormal returns than are produced by single sorts. This is true, but only on the short side. Double sorts do not generate larger long-side alphas than do single sorts.

Option-based measures of stock mispricing are good at identifying frictions that slow the response of stock prices to information in options. The mispriced stocks are often small or hard-to-borrow. Some of these measures, however, seem to predict realizable if modest positive abnormal returns.

Table 1.

Implicit leverage in Options

Panel A. Mean leverage for call options. Implicit leverage is calculated from the Black-Scholes model as $Leverage\ = [e^{-rT}KN(d2)]/[(S-PVDIV)*N(d1)]$ where $d1 = \frac{\log\left(\frac{(S-PVDIV)}{K}\right)+(r+\sigma^2/2)*T}{\sigma\sqrt{T}}$ $and\ d2 = d1-\sigma\sqrt{T},$ S is the stock price, $PVDIV$ is the present value of dividends paid over the life of the option, K is the strike price, r is the risk free interest rate, σ is the stock volatility, T is the time to expiration, and N(.) is the cumulative normal distribution.

	≤ 30 Days to Expiration	30 – 179 Days to Expiration	≥ 180 Days to Expiration
In the Money	0.8450	0.7662	0.6570
At the Money	0.8835	0.8310	0.7678
Out of the Money	0.9154	0.8809	0.8393

Panel B. Mean put collateral requirements. The implicit collateral for puts is

$$Percent\ Collateral = \frac{e^{-rT}KN(-d2)-(S-PVDIV)N(-d1)}{(S-PVDIV)N(-d1)}$$

In the Money	0.1970	0.3782	0.6180
At the Money	0.1416	0.2363	0.3933
Out of the Money	0.1183	0.2037	0.3595

Table 2.

Panel A. The distribution of the number of contracts traded per month.

	Mean	Median	Std. Dev.	Minimum	Maximum
	All Stocks with Options				
≥ 10 and ≤ 30 Days to Expiration	482	226	1,334	1	147,196
> 30 and ≤ 60 Days to Expiration	378	194	893	0	104,670
> 60 and ≤ 90 Days to Expiration	335	154	892	1	100,634
> 90 Days to Expiration	288	142	585	0	43,873
	500 Largest Stocks				
≥ 10 and ≤ 30 Days to Expiration	806	385	2,044	1	127,942
> 30 and ≤ 60 Days to Expiration	552	293	1,369	0	104,670
> 60 and ≤ 90 Days to Expiration	442	212	1,263	1	100,634
> 90 Days to Expiration	366	197	719	3	43,873

Panel B. Summary statistics for option-based measures of stock mispricing

	Mean	Median	Std. Dev.	Minimum	Maximum
Measures Based on Differences Between Actual and Implied Stock Prices					
IPD	-0.135	-0.035	1.952	-96.526	78.817
Implied Fee	0.008	0.005	0.037	-1.551	0.914
Measures Based on Implied Volatilities					
CW	-0.012	-0.006	0.069	-2.169	2.039
ΔCVOL	-0.001	-0.002	0.164	-2.562	2.544
ΔPVOL	-0.001	-0.002	0.165	-2.598	2.749
Skewness	0.064	0.048	0.076	-0.885	2.218
Measures Based on Trading Volume					
PP	0.567	0.542	0.265	0.000	1.000
OOI	-0.000	0.000	0.001	-0.091	0.083
O/S	0.090	0.051	0.144	0.000	17.283

Panel C. Indicative stock borrowing fees. Fees are averaged across firms for the year. The distribution is of stock annual average fees.

Year	Stocks	1st Percentile	Median	80th Percentile	99th Percentile
2004	3,295	0.375	0.482	0.625	6.941
2005	3,875	0.409	0.476	0.804	11.125
2006	4,109	0.392	0.464	1.352	12.838
2007	4,237	0.387	0.458	1.181	12.161
2008	4,086	0.391	0.469	1.839	17.161
2009	3,931	0.271	0.338	0.710	24.474
2010	3,936	0.335	0.373	0.897	32.819
2011	4,008	0.367	0.381	1.750	47.899
2012	3,924	0.371	0.397	1.885	41.131
2013	3,874	0.372	0.392	1.720	39.032

Table 3. Characteristics of portfolios formed from option-based mispricing measures.

Panel A. Average firm sizes. Firm sizes, in billions of dollars are calculated for each portfolio each month and then averaged across months.

	Measures from Difference in Implied and Actual Stock Prices		Measures from Implied Volatilities				Measures from Option and Stock Volume		
Port.	IPD	Implied Fees	CW	ΔCVOL	ΔPVOL	Skewness	Pan Poteshman	OOI	O/S
Low	\$2.75	\$9.30	\$3.08	\$4.38	\$4.49	\$8.16	\$15.18	\$7.45	\$3.08
2	\$7.96	\$12.49	\$7.65	\$8.57	\$8.51	\$13.58	\$17.83	\$11.26	\$7.65
3	\$13.82	\$10.16	\$10.31	\$10.43	\$10.24	\$8.36	\$9.33	\$3.53	\$10.31
4	\$12.12	\$4.82	\$9.82	\$8.94	\$8.99	\$4.21	\$4.89	\$9.72	\$9.82
High	\$5.32	\$1.70	\$5.66	\$4.61	\$4.82	\$2.65	\$2.65	\$7.17	\$5.66

Panel B. The proportion of stocks in quintile portfolios formed on option-based mispricing measures that are hard to borrow.
A stock is defined as hard-to-borrow if the stock's indicative borrowing fee from Markit is among the highest 20% across all stocks.

	Measures from Difference in Implied and Actual Stock Prices		Measures from Implied Volatilities				Measures from Option and Stock Volume		
Port.	IPD	Implied Fees	CW	ΔCVOL	ΔPVOL	Skewness	Pan Poteshman	OOI	O/S
Low	33.88%	5.56%	37.07%	17.50%	17.92%	15.96%	18.41%	16.59%	6.69%
2	11.20%	3.13%	6.98%	8.97%	8.99%	7.65%	10.78%	7.41%	8.58%
3	5.26%	3.36%	3.84%	7.41%	7.36%	8.57%	10.70%	11.15%	10.62%
4	4.99%	5.92%	3.64%	8.64%	8.19%	12.57%	10.87%	9.59%	13.35%
High	10.74%	30.72%	12.34%	17.05%	17.13%	15.50%	10.01%	17.15%	21.13%

Table 4. Value-weighted portfolios formed from all stocks with options.

Each month over 2004-2013, stocks are sorted into quintiles based on option based measures of stock mispricing. IPD is the average percentage difference between implied and actual stock prices. Implied borrowing fees is the stock borrowing fee implied by violations of put-call parity. CW is the difference between implied volatilities of calls and puts. Skewness is the difference in implied volatilities of a put with a delta of 0.2 and a call with a delta of 0.5. ΔPVOL is the monthly change in implied volatilities for 30 day puts with deltas of -0.5. ΔCVOL is the change analogous change in call implied volatilities. PP is the ratio of put buy volume that opens positions to the sum of put and call buy volume. OOI is the difference between synthetic positive and negative options volume. O/S is the natural logarithm of the ratio of stock and options volume. The Fama-French-Carhart four factor model is used to calculate α's. Newey-West adjusted standard errors with three lags are used. Returns and α's are in percentages.

Panel A. Measures based on the difference between implied and actual stock prices

Sort on implied price difference (IPD).

Port.	R_{t+1}	α_{t+1}	T Stat.	R_{t+2}	α_{t+2}	T Stat.	R_{t+3}	α_{t+3}	T Stat.
Low	0.3543	-0.3810	-2.33	0.3887	-0.4061	-2.34	0.4275	-0.4094	-1.92
2	0.4851	-0.1244	-1.25	0.4884	-0.1466	-1.20	0.4833	-0.2030	-1.89
3	0.4759	-0.0934	-1.51	0.4651	-0.1472	-2.09	0.5602	-0.1160	-1.76
4	0.7056	0.1628	2.48	0.7303	0.1618	1.82	0.7514	0.1572	1.81
High	0.8748	0.2553	2.95	1.0216	0.3875	3.75	1.0427	0.4299	3.52
H-L	0.5205	0.6364	3.31	0.6329	0.7936	3.59	0.6151	0.8392	2.89

Sort on implied stock borrowing fees

Port.	R_{t+1}	α_{t+1}	T Stat.	R_{t+2}	α_{t+2}	T Stat.	R_{t+3}	α_{t+3}	T Stat.
Low	0.6517	0.1298	1.59	0.5051	-0.0357	-0.32	0.6575	0.0776	0.57
2	0.6525	0.0961	1.39	0.5722	-0.0077	-0.14	0.6479	0.0582	0.69
3	0.4827	-0.1078	-1.96	0.7039	0.0658	0.97	0.5866	-0.0570	-0.93
4	0.5816	-0.0656	-0.52	0.6339	-0.0443	-0.45	0.5891	-0.1253	-1.04
High	0.3621	-0.3873	-2.65	0.4931	-0.3061	-2.27	0.4698	-0.3829	-2.37
H-L	-0.2896	-0.5171	-2.87	-0.0121	-0.2704	-1.54	-0.1877	-0.4604	-2.31

Panel B. Measures based on implied volatilities

Portfolios formed on Cremers-Weinbaum (CW)

Port.	R_{t+1}	α_{t+1}	T Stat.	R_{t+2}	α_{t+2}	T Stat.	R_{t+3}	α_{t+3}	T Stat.
Low	0.5901	-0.1406	-0.96	0.7604	0.0015	0.01	0.6582	-0.1163	-0.70
2	0.5256	-0.0804	-0.59	0.5538	-0.0900	-0.69	0.6023	-0.0387	-0.35
3	0.6532	0.1068	1.68	0.6629	0.0965	1.25	0.6562	0.0469	0.71
4	0.5100	-0.0546	-0.66	0.5427	-0.0543	-0.71	0.5315	-0.0872	-0.94
High	0.5645	-0.0820	-0.50	0.7768	0.0694	0.41	0.6924	-0.0397	-0.21
H-L	-0.0256	0.0586	0.25	0.0165	0.0679	0.27	0.0343	0.0766	0.26

Portfolios formed on skewness

Port.	R_{t+1}	α_{t+1}	T Stat.	R_{t+2}	α_{t+2}	T Stat.	R_{t+3}	α_{t+3}	T Stat.
Low	0.7612	0.1844	1.45	0.7804	0.2002	1.39	0.9092	0.2952	2.00
2	0.6021	0.0918	1.69	0.6620	0.1141	1.46	0.6393	0.0780	1.23
3	0.6423	0.0468	0.49	0.5790	-0.0559	-0.52	0.6261	-0.0273	-0.24
4	0.6836	0.0366	0.28	0.8197	0.1198	1.10	0.7085	0.0261	0.22
High	0.4510	-0.2096	-1.28	0.3976	-0.2835	-1.41	0.4417	-0.3091	-1.67
H-L	-0.3102	-0.3940	-1.77	-0.3828	-0.4837	-2.03	-0.4675	-0.6044	-2.30

Table 4, Panel B (Continued)

Portfolios formed on changes in implied volatilities of call options (ΔCVOL).

Port.	R_{t+1}	α_{t+1}	T Stat.	R_{t+2}	α_{t+2}	T Stat.	R_{t+3}	α_{t+3}	T Stat.
Low	0.5607	-0.0641	-0.35	0.5975	-0.1296	-0.72	1.0120	0.2698	1.34
2	0.6190	0.1046	1.14	0.7728	0.1269	1.34	0.5353	-0.1086	-0.99
3	0.6078	0.0655	0.71	0.6925	0.0915	1.11	0.7050	0.1068	1.13
4	0.6086	0.0222	0.18	0.5605	-0.0513	-0.48	0.5791	-0.0856	-0.73
High	0.3618	-0.4087	-2.24	0.6098	-0.1354	-0.88	0.5897	-0.1975	-0.96
H-L	-0.1988	-0.3447	-1.21	0.0123	-0.0058	-0.03	-0.4224	-0.4674	-1.39

Portfolios formed on changes in implied volatilities of put options (ΔPVOL).

Port.	R_{t+1}	α_{t+1}	T Stat.	R_{t+2}	α_{t+2}	T Stat.	R_{t+3}	α_{t+3}	T Stat.
Low	0.8217	0.2038	1.29	0.6306	-0.1042	-0.61	1.0225	0.2867	1.89
2	0.6273	0.1231	1.12	0.7736	0.1549	1.51	0.6471	0.0122	0.11
3	0.6012	0.0764	1.01	0.6994	0.1090	1.23	0.7262	0.1243	1.54
4	0.6455	0.0483	0.52	0.5376	-0.0855	-0.72	0.5172	-0.1420	-1.78
High	0.2555	-0.5231	-3.21	0.6599	-0.0810	-0.60	0.4974	-0.3325	-2.00
H-L	-0.5662	-0.7269	-2.73	0.0293	0.0232	0.10	-0.5252	-0.6192	-2.36

Panel C. Sorts based on option trades and volume

Portfolios formed on Pan and Poteshman

Port.	R_{t+1}	α_{t+1}	T Stat.	R_{t+2}	α_{t+2}	T Stat.	R_{t+3}	α_{t+3}	T Stat.
Low	0.5498	-0.0758	-0.63	0.6181	-0.0524	-0.49	0.6122	-0.0759	-0.70
2	0.6045	0.0524	0.78	0.5450	-0.0385	-0.64	0.6292	0.0227	0.44
3	0.5775	0.0061	0.07	0.5735	-0.0418	-0.43	0.5922	-0.0488	-0.42
4	0.6404	0.0272	0.27	0.7123	0.0999	1.03	0.5782	-0.1312	-1.16
High	0.6073	-0.0379	-0.33	0.7283	0.0421	0.37	0.7843	0.0878	0.81
H-L	0.0575	0.0378	0.18	0.1102	0.0944	0.51	0.1721	0.1637	0.90

Portfolios formed on Options Order Imbalance

Port.	R_{t+1}	α_{t+1}	T Stat.	R_{t+2}	α_{t+2}	T Stat.	R_{t+3}	α_{t+3}	T Stat.
Low	0.5066	-0.1470	-1.42	0.6312	-0.0309	-0.26	0.5803	-0.1599	-1.24
2	0.6168	0.1003	1.54	0.6018	0.0619	0.73	0.6056	0.0094	0.14
3	0.5303	-0.0551	-0.48	0.7245	0.1179	1.15	0.7687	0.1664	1.77
4	0.5565	0.0148	0.13	0.7313	0.1268	1.31	0.7781	0.1686	2.14
High	0.6658	-0.0437	-0.34	0.4304	-0.3469	-2.70	0.6155	-0.1287	-1.06
H-L	0.1593	0.1032	0.57	-0.2008	-0.3160	-1.65	0.0352	0.0313	0.15

Sorted on O/S

Port.	R_{t+1}	α_{t+1}	T Stat.	R_{t+2}	α_{t+2}	T Stat.	R_{t+3}	α_{t+3}	T Stat.
Low	0.8463	0.2560	3.81	0.8914	0.2675	3.21	0.8955	0.2688	3.74
2	0.8082	0.1873	2.54	0.8840	0.2388	2.69	0.9105	0.2383	2.68
3	0.7696	0.1531	2.17	0.8006	0.1623	1.95	0.7604	0.1226	1.82
4	0.6993	0.1066	1.33	0.6941	0.0676	0.81	0.7751	0.1553	2.02
High	0.3645	-0.1854	-4.37	0.3877	-0.2005	-2.41	0.3971	-0.2311	-3.94
H-L	-0.4818	-0.4414	-4.73	-0.5037	-0.4680	-5.62	-0.4984	-0.5019	-4.73

Table 5. Four-factor average alphas for quintile portfolios formed on the basis of option-based measures of stock mispricing when the portfolio include and exclude hard-to-borrow stocks. A stock is defined as hard-to-borrow if the indicative fee to borrow the stock is among the highest 20% across all stocks. Alphas are in percent (i.e. 0.61 is 61 basis points) and are for the first three months following portfolio formation. T-statistics are in parentheses under the alphas. They are calculated using Newey-West adjusted standard errors with three lags.

Panel A. Measures based on the difference between implied and actual stock prices.

	α_{t+1}		α_{t+2}		α_{t+3}	
	Include	Exclude	Include	Exclude	Include	Exclude
Stocks Sorted on IPD						
Low	-0.3810	-0.0597	-0.4061	0.0635	-0.4094	-0.1291
	(-2.33)	(-0.33)	(-2.34)	(0.36)	(-1.92)	(-0.78)
High	0.2553	0.3412	0.3875	0.4562	0.4299	0.5003
	(2.95)	(3.78)	(3.75)	(3.96)	(3.52)	(3.77)
High-Low	0.6364	0.4009	0.7936	0.3926	0.8392	0.6294
	(3.31)	(1.93)	(3.59)	(1.88)	(2.89)	(2.72)
Stocks Sorted on Implied Fees						
Low	0.1298	0.2615	-0.0357	0.0314	0.0776	0.1758
	(1.59)	(3.09)	(-0.32)	(0.29)	(0.57)	(1.14)
High	-0.3873	-0.0499	-0.3061	0.0173	-0.3829	0.0088
	(-2.65)	(-0.33)	(-2.27)	(0.13)	(-2.37)	(0.05)
High-Low	-0.5171	-0.3114	-0.2704	-0.0141	-0.4604	-0.1670
	(-2.87)	(-1.61)	(-1.54)	(-0.08)	(-2.31)	(-0.68)

Panel B. Measures based on difference in implied volatilities across options or over time.

	α_{t+1}		α_{t+2}		α_{t+3}	
	Include	Exclude	Include	Exclude	Include	Exclude
Stocks Sorted on CW						
Low	-0.1406	-0.0336	0.0015	0.2507	-0.1163	-0.0173
	(-0.96)	(-0.25)	(0.01)	(1.98)	(-0.70)	(-0.14)
High	-0.0820	0.0446	0.0694	0.1984	-0.0397	0.1999
	(-0.50)	(0.23)	(0.41)	(1.17)	(-0.21)	(1.26)
High-Low	0.0586	0.0783	0.0679	-0.0523	0.0766	0.2172
	(0.25)	(0.30)	(0.27)	(-0.22)	(0.26)	(0.96)
Stocks Sorted on Skewness						
Low	0.1844	0.2682	0.2002	0.2171	0.2952	0.2882
	(1.45)	(2.18)	(1.39)	(1.62)	(2.00)	(1.94)
High	-0.2096	-0.0178	-0.2835	0.0597	-0.3091	-0.1068
	(-1.28)	(-0.11)	(-1.41)	(0.38)	(-1.67)	(-0.70)
High-Low	-0.3940	-0.2861	-0.4837	-0.1574	-0.6044	-0.3950
	(-1.77)	(-1.29)	(-2.03)	(-0.76)	(-2.30)	(-1.64)
Stocks Sorted on ΔCVOL						
Low	-0.0641	0.0325	-0.1296	0.0763	0.2698	0.2432
	(-0.35)	(0.20)	(-0.72)	(0.45)	(1.34)	(1.30)
High	-0.4087	-0.2080	-0.1354	-0.0084	-0.1975	-0.1832
	(-2.24)	(-1.16)	(-0.88)	(-0.06)	(-0.96)	(-0.88)
High-Low	-0.3447	-0.2405	-0.0058	-0.0846	-0.4675	-0.4264
	(-1.21)	(-0.89)	(-0.03)	(-0.39)	(-1.39)	(-1.27)

			Stocks Sorted on ΔPVOL			
Low	0.2038	0.2300	-0.1042	0.0072	0.2867	0.3099
	(1.29)	(1.54)	(-0.61)	(0.05)	(1.89)	(2.03)
High	-0.5231	-0.3885	-0.0810	0.0637	-0.3325	-0.2513
	(-3.21)	(-2.47)	(-0.60)	(0.50)	(-2.00)	(-1.58)
High-Low	-0.7269	-0.6185	0.0232	0.0565	-0.6192	-0.5611
	(-2.73)	(-2.35)	(0.10)	(0.26)	(-2.36)	(-2.17)

Panel C. Measures based on option trading or volume.

	α_{t+1}		α_{t+2}		α_{t+3}	
	Include	Exclude	Include	Exclude	Include	Exclude
			Stocks Sorted on OOI			
Low	-0.1470	-0.1051	-0.0309	0.0585	-0.1599	-0.0612
	(-1.42)	(-1.02)	(-0.26)	(0.53)	(-1.24)	(-0.55)
High	-0.0437	0.1434	-0.3469	-0.1844	-0.1287	-0.0180
	(-0.34)	(1.09)	(-2.70)	(-1.45)	(-1.06)	(-0.13)
High-Low	0.1032	0.2486	-0.3160	-0.2429	0.0313	0.0433
	(0.57)	(1.32)	(-1.65)	(-1.32)	(0.15)	(0.21)
			Stocks Sorted on PP			
Low	-0.0758	0.0597	-0.0524	0.0182	-0.0759	-0.0827
	(-0.63)	(0.47)	(-0.49)	(0.19)	(-0.70)	(-0.81)
High	-0.0379	-0.0002	0.0421	0.0111	0.0878	0.1134
	(-0.33)	(0.00)	(0.37)	(0.93)	(0.81)	(0.99)
High-Low	0.0378	-0.0599	0.0944	0.0929	0.1637	0.1961
	(0.18)	(-0.28)	(0.51)	(0.51)	(0.90)	(1.07)
			Stocks Sorted on O/S			
Low	0.2560	0.2741	0.2675	0.2993	0.2688	0.2905
	(3.81)	(3.90)	(3.21)	(3.75)	(3.74)	(3.87)
High	-0.1854	-0.0662	-0.2005	-0.0714	-0.2311	-0.1128
	(-4.37)	(-1.55)	(-2.41)	(-1.81)	(-3.94)	(-2.37)
High-Low	-0.4414	-0.3402	-0.4680	-0.3706	-0.5019	-0.4033
	(-4.73)	(-3.57)	(-5.62)	(-3.57)	(-4.73)	(-4.03)

Table 6. Fama-French four factor alphas for the 12 months following portfolio formation for quintile portfolios formed on option-based measures of stock mispricing. Portfolios are value-weighted. Average alphas for the high and low quintile portfolios, along with the difference in alphas are reported. The sample period is 2004-2013. IPD is the average percentage difference between implied and actual stock prices. Implied borrowing fees is the stock borrowing fee implied by violations of put-call parity. Skewness is the difference in implied volatilities of a put with a delta of 0.2 and a call with a delta of 0.5. O/S is the natural logarithm of the ratio of stock and options volume. The Fama-French-Carhart four factor model is used to calculate α's. Newey-West adjusted standard errors with three lags are used. Returns and α's are in percentages.

	IPD			Skewness			O/S		
Month	High	Low	H-L	High	Low	H-L	High	Low	H-L
t+1	0.2553	-0.3810	0.6364	-0.2096	0.1844	-0.3940	-0.1854	0.2560	-0.4414
	(2.95)	(-2.33)	(3.31)	(-1.28)	(1.45)	(-1.77)	(-4.37)	(3.81)	(-4.73)
t+2	0.3875	-0.4061	0.7936	-0.2835	0.2002	-0.4837	-0.2005	0.2675	-0.4680
	(3.75)	(-2.34)	(3.59)	(-1.41)	(1.39)	(-2.03)	(-4.30)	(3.53)	(-4.76)
t+3	0.4299	-0.4094	0.8392	-0.3091	0.2952	-0.6044	-0.2331	0.2688	-0.5019
	(3.52)	(-1.92)	(2.89)	(-1.67)	(2.00)	(-2.30)	(-3.94)	(3.74)	(-4.73)
t+4	0.3379	-0.4127	0.7506	-0.2865	0.4246	-0.7110	-0.1953	0.2728	-0.4681
	(3.18)	(-1.53)	(2.58)	(-1.24)	(2.62)	(-2.20)	(-3.28)	(3.56)	(-4.24)
t+5	0.3059	-0.6516	0.9575	-0.4286	0.4739	-0.9025	-0.1934	0.2135	-0.4068
	(3.13)	(-2.11)	(2.80)	(-1.61)	(3.04)	(-2.66)	(-3.03)	(2.49)	(-3.57)
t+6	0.5547	-0.3136	0.8683	-0.3205	0.3658	-0.6864	-0.1873	0.2021	-0.3894
	(7.16)	(-1.23)	(3.07)	(-1.40)	(2.13)	(-2.07)	(-3.04)	(2.72)	(-3.93)
t+7	0.1334	-0.1236	0.2570	-0.2575	0.1835	-0.4410	-0.1252	0.2436	-0.3688
	(1.33)	(-0.54)	(0.94)	(-1.25)	(1.33)	(-1.52)	(-2.07)	(3.40)	(-3.60)
t+8	-0.0687	0.0855	-0.1542	-0.0488	0.1066	-0.1554	-0.1179	0.2319	-0.3498
	(-0.60)	(0.36)	(-0.57)	(-0.26)	(0.81)	(-0.59)	(-1.74)	(2.83)	(-3.32)
t+9	0.0527	0.0499	0.0028	-0.1092	0.2991	-0.4082	-0.1378	0.1845	-0.3223
	(0.42)	(0.21)	(0.01)	(-0.48)	(1.87)	(-1.26)	(-2.31)	(2.19)	(-2.94)
t+10	0.1536	-0.3196	0.4732	-0.1881	0.1998	-0.3879	-0.0935	0.1117	-0.2051
	(1.13)	(-2.08)	(2.25)	(-0.81)	(1.51)	(-1.46)	(-1.45)	(1.52)	(-1.87)
t+11	0.1692	-0.0545	0.2237	-0.1086	0.0118	-0.1204	-0.1010	0.2051	-0.3061
	(1.31)	(-0.30)	(0.91)	(-0.51)	(0.08)	(-0.46)	(-1.46)	(2.33)	(-2.80)
t+12	0.3895	0.3044	0.0852	-0.0381	-0.0782	0.0401	-0.1497	0.1860	-0.3357
	(2.79)	(1.07)	(0.27)	(-0.16)	(-0.60)	(0.14)	(-2.08)	(2.44)	(-3.33)
Sum	3.1009	-2.6323	5.7333	-2.5881	2.6667	-5.2548	-1.9201	2.6435	-4.5634

Table 7. Sharpe ratios of value-weighted quintile portfolios of underpriced stocks formed using IPD, O/S, and skewness. Each month over 2004-2013, stocks are sorted into five quintiles for each of the mispricing measures: IPD, O/S, and skewness. For the high IPD, low O/S, and low skewness quintile portfolios, Sharpe ratios are calculated for each of the following 12 months. The excess return for the 1st month after portfolio formation is computed by subtracting the risk-free rate from the portfolio return. The time-series average monthly excess return for the first month after portfolio formation is divided by the time series standard deviation of first month excess returns to calculate the Sharpe ratio for the first month. Sharpe ratios for months 2-12 are calculated analogously. For comparison, the mean monthly Sharpe ratio is 0.1219 for the S&P 500 and 0.1236 for the CRSP value-weighted index over the same period.

	IPD	O/S	Skewness
T+1	0.1804	0.1858	0.1591
T+2	0.2114	0.1891	0.1625
T+3	0.2245	0.1943	0.1875
T+4	0.2096	0.1948	0.2184
T+5	0.2022	0.1843	0.2240
T+6	0.2575	0.1805	0.1981
T+7	0.1708	0.1896	0.1838
T+8	0.1378	0.1932	0.1742
T+9	0.1547	0.1742	0.1952
T+10	0.1721	0.1632	0.1876
T+11	0.1718	0.1711	0.1433
T+12	0.2132	0.1670	0.1196

Table 8. Correlations of monthly quintile portfolio assignments for various measures of option-based stock mispricing. IPD is the average percentage difference between implied and actual stock prices. Implied borrowing fees is the stock borrowing fee implied by violations of put-call parity. CW is the difference between implied volatilities of calls and puts. Skewness is the difference in implied volatilities of a put with a delta of 0.2 and a call with a delta of 0.5. ΔPVOL is the monthly change in implied volatilities for 30 day puts with deltas of -0.5. ΔCVOL is the change analogous change in call implied volatilities. PP is the ratio of put buy volume that opens positions to the sum of put and call buy volume. OOI is the difference between synthetic positive and negative options volume. O/S is the natural logarithm of the ratio of stock and options volume.

	Basis of Option Based Mispricing Measure								
	Implied - Actual Stock Prices		Implied Volatilities				Option and Stock Trading Volume		
	IPD	Imp Fee	CW	ΔCVOL	ΔPVOL	Skew	PP	OOI	O/S
IPD	1.000								
Imp Fee	-0.232	1.000							
CW	0.216	-0.500	1.000						
ΔCVOL	0.031	-0.046	0.052	1.000					
ΔPVOL	0.031	-0.005	0.019	0.570	1.000				
Skew	-0.097	0.175	-0.205	-0.037	-0.034	1.000			
PP	-0.063	0.067	-0.042	0.013	0.015	0.172	1.000		
OOI	0.054	-0.081	0.110	0.061	0.047	-0.084	-0.155	1.000	
O/S	-0.057	0.020	-0.091	0.012	0.015	-0.067	-0.317	-0.040	1.000

Table 9.
Fama-French four factor alphas for the first month after portfolio formation for portfolios based on double sorts of option-based measures of stock mispricing. T-statistics are shown in parentheses under alphas.

All stocks, value-weighted portfolios.

	Low O/S	2	3	4	High O/S	High - Low
Low IPD	0.1527	-0.1766	-0.0408	-0.7992	-0.9631	-1.1158
	(1.07)	(-0.80)	(-0.19)	(-2.16)	(-2.43)	(-2.69)
2	0.3163	0.0535	0.2865	-0.2075	-0.5291	-0.8453
	(3.04)	(0.31)	(1.68)	(-1.14)	(-1.97)	(-2.60)
3	0.3095	0.0712	-0.1250	0.1403	-0.1861	-0.4957
	(2.87)	(0.57)	(-0.82)	(0.98)	(-1.42)	(-2.62)
4	0.0554	0.1330	0.2802	0.2251	-0.0715	-0.1270
	(0.43)	(0.82)	(2.13)	(1.87)	(-0.53)	(-0.71)
High IPD	0.2207	0.4794	0.4487	0.2202	0.3261	0.1054
	(1.56)	(3.41)	(2.75)	(1.09)	(1.49)	(0.38)
High - Low	0.0680	0.6560	0.4895	1.0194	1.2892	
	(0.36)	(2.70)	(1.77)	(2.35)	(2.93)	

Panel B. Portfolios formed from double sorts of stocks on IPD and skewness.
All stocks, value-weighted portfolios

	Low Skew	2	3	4	High Skew	High - Low
Low IPD	0.2179	0.1765	-0.4943	-1.1891	-0.3788	-0.5967
	(0.78)	(0.76)	(-2.23)	(-3.99)	(-1.34)	(-1.49)
2	-0.0288	0.0159	-0.0762	0.0229	-0.3480	-0.3192
	(-0.18)	(0.09)	(-0.36)	(0.11)	(-1.29)	(-1.08)
3	0.1307	0.2233	-0.0739	0.1176	-0.2561	-0.3868
	(0.86)	(1.69)	(-0.54)	(0.67)	(-1.47)	(-1.50)
4	0.2534	0.0329	-0.0310	0.1503	0.2119	-0.0415
	(1.42)	(0.25)	(-0.21)	(0.82)	(1.00)	(-0.14)
High IPD	0.1490	0.1495	0.5096	0.2680	0.3820	0.2330
	(0.57)	(0.92)	(3.09)	(1.62)	(1.90)	(0.74)
High - Low	-0.0689	-0.0270	1.0039	1.4570	0.7608	
	(-0.18)	(-0.09)	(3.68)	(4.07)	(2.17)	

Panel C. Portfolios formed from double sorts of stocks on implied borrowing fees and skewness.

All Stocks (VW)

	Low Skew	2	3	4	High Skew	High - Low
Low Imp. Fee	0.0039	0.2930	0.3379	0.3641	-0.1953	-0.1991
	(0.02)	(1.96)	(2.05)	(1.62)	(-0.75)	(-0.61)
2	0.2416	0.0946	0.3048	0.0671	0.3675	0.1259
	(1.51)	(0.69)	(2.54)	(0.33)	(1.81)	(0.43)
3	0.2489	0.0224	-0.3119	-0.0617	-0.2961	-0.5451
	(1.71)	(0.16)	(-2.06)	(-0.36)	(-1.24)	(-1.76)
4	-0.0931	-0.0134	0.1280	-0.2074	-0.1196	-0.0265
	(-0.48)	(-0.08)	(0.69)	(-1.12)	(-0.37)	(-0.09)
High Imp. Fee	0.1257	-0.3088	-0.6165	-0.5463	-0.6580	-0.7837
	(0.52)	(-1.47)	(-3.12)	(-1.93)	(-2.01)	(-2.22)
High - Low	0.1218	-0.6018	-0.954	-0.9104	-0.4628	
	(0.37)	(-2.14)	(-3.55)	(-2.66)	(-1.43)	

Table 10

Percentage of stocks in portfolio that are hard-to-borrow. Hard-to-borrow is defined as having borrowing fees that are among the highest 20% across all stocks.

Panel A. Portfolios formed by double sorts on the log of the ratio of option to stock volume (O/S), and on the percentage difference between the actual stock price and the price implied by options (IPD).

	Low O/S	2	3	4	High O/S
Low IPD	12.3%	19.5%	28.0%	41.5%	65.3%
2	4.5%	6.5%	8.9%	13.4%	20.4%
3	3.5%	3.9%	5.2%	5.4%	7.5%
4	3.6%	3.9%	4.5%	5.5%	6.6%
High IPD	6.4%	8.0%	9.0%	10.6%	14.9%

Panel B. Portfolios formed by double sorts on skewness, measured as the difference between the implied volatility of a short-term out-of-the-money put and the implied volatility of an at-the-money call, and the percentage difference between the actual stock price and the price implied by options (IPD).

	Low Skewness	2	3	4	High Skewness
Low IPD	30.9%	25.8%	29.7%	38.0%	41.7%
2	12.1%	7.8%	9.5%	11.7%	13.8%
3	6.5%	3.6%	3.6%	4.9%	7.3%
4	6.2%	3.6%	3.5%	4.2%	7.0%
High IPD	19.3%	7.7%	6.6%	8.2%	10.0%

Panel C. Portfolios formed by double sorts on skewness, measured as the difference between the implied volatility of a short-term out-of-the-money put and the implied volatility of an at-the-money call, and implied stock borrowing fees estimated from put-call parity violations.

	Low Skewness	2	3	4	High Skewness
Low Fees	8.8%	4.6%	4.0%	5.0%	5.4%
2	3.9%	2.5%	2.7%	3.1%	3.5%
3	3.9%	2.8%	2.8%	3.4%	3.8%
4	6.8%	5.5%	5.4%	5.6%	6.0%
High Fees	26.5%	28.4%	32.9%	34.3%	31.0%

References

An, Byeong-Je, Andrew Ang, Turan Bali, and Nusret Cakici, 2014, The joint cross section of stocks and options, Journal of Finance 59 (5), 2279-2337.

Baker, Malcolm, and Jeffrey Wurgler, 2006, Investor sentiment and the cross-section of stock returns, Journal of Finance 55, 2219-2257.

Battalio, Robert, and Paul Schultz, 2011, Regulatory uncertainty and market liquidity: The 2008 short sale ban's impact on equity option markets, Journal of finance 66 (6), 2013-2053.

Bollen, Nicolas and Robert Whaley, 2004, Does net buying pressure affect the shape of implied volatility functions? Journal of Finance 59 (2), 711-753.

Chakravarty, Sugato, Huseyin Gulen, and Stewart Mayhew, 2004, Informed trading in stock and option markets, Journal of Finance 59, 1235-1257.

Christofferson, Peter, Ruslan Goyenko, Kris Jacobs, and Mehdi Karoui, 2018, Illiquidity Premia in the Equity Options Market, Review of Financial Studies 31 (3), 811-851.

Clements, Mark, Vitali Kalesnik, and Juhani Linnainmaa, 2017, Informed traders, long-date options, and the cross section of stock returns, working paper, University of Southern California.

Cremers, Martijn, and David Weinbaum, 2010, Deviations from put-call parity and stock return predictability, Journal of Financial and Quantitative Analysis 45(2), 335-367.

Dimson, Elroy, 1979, Risk measurement when shares are subject to infrequent trading, Journal of Financial Economics 7, 197-226.

Easley, David, Nicholas Kiefer, Maureen O'Hara, and Joseph Paperman, 1996, Liquidity, information, and infrequently traded stocks, Journal of Finance 51 (4), 1405-1436.

Easley, David, Maureen O'Hara, and P.S. Srinivas, 1998, Option volume and stock prices: Evidence on where informed traders trade, Journal of Finance 53, 431-465.

Fama, Eugene, and Kenneth French, 2008, Dissecting anomalies. Journal of Finance 63 (4), 1653-1678.

Fama, Eugene, and James MacBeth, 1973, Risk, return and equilibrium: Empirical tests, Journal of Political Economy 81 (3), 607-636.

Figlewski, Stephen, and Gwendolyn Webb, 1993, Options, short-sales, and market completeness, Journal of Finance 48 (2), 761-777.

Gaspar, Jose-Miguel, Massimo Massa, and Pedro Matos (2005), Shareholder investment horizons and the market for corporate control. Journal of Financial Economics 76, 135-165.

Ge, Li, Tse-Chun Lin, and Neil Pearson, 2016, Why does the option to stock volume ratio predict stock returns? Journal of Financial Economics 120, 601-622.

Hu, Jianfeng, 2014, Does option trading convey stock price information? Journal of Financial Economics 111, 625-645.

Jacobs, Heiko, 2015, What explains the dynamics of 100 anomalies? Journal of Banking and Finance 57, 65-85.

Johnson, Travis and Eric So, 2012, The option to stock volume ratio and future returns, Journal of Financial Economics 106, 262-286.

Kacperczyk, Marcin, and Emiliano Pagnotta, 2018, Chasing private information, working paper, Imperial College London.

Lee, Charles, and Mark Ready, 1991, Inferring trade direction from intraday data, Journal of Finance 46, 733-746.

Manaster, Steven and Richard Rendleman, 1982, Option prices as predictors of equilibrium stock prices, Journal of Finance 37 (4), 1043-1057.

Muravyev, Dmitriy, and Neil Pearson, 2019, Option trading costs are lower than you think, working paper, University of Illinois.

Muravyev, Dmitriy, Neil Pearson, and John Broussard, 2013, Is there price discovery in equity options?, Journal of Financial Economics 107, 259-283.

Muravyev, Dmitriy, Neil Pearson, and Joshua Pollet, 2018, Understanding returns to short-selling using option implied stock borrowing fees, working paper, University of Illinois.

Ni, Sophie, Jun Pan, and Allen Poteshman, 2008, Volatility information trading in the option market, Journal of Finance 63, 1059-1091.

Pan, Jun and Allen Poteshman, 2006, The information in option volume for future stock prices, Review of Financial Studies 19 (3), 871-908.

Roll, Richard, Eduardo Schwartz, and Avanidhar Subrahmanyam, 2010, O/S: The relative trading activity in options and stock, Journal of Financial Economics 96, 1-17.

Stambaugh, Robert, Jianfeng Yu, and Yu Yuan, 2015, Arbitrage asymmetry and the idiosyncratic volatility puzzle, Journal of Finance 70, 1903-1948.

Xing, Yuhang, Xiaoyan Zhang, and Rui Zhao, 2010, What does the individual option volatility smirk tell us about future equity returns? Journal of Financial and Quantitative Analysis 45 (3), 641-662.

Appendix. Returns to equal-weighted portfolios of stocks sorted on option-based measures of mispricing

Table A1 reports returns and four-factor Fama-French-Carhart alphas for equal-weighted quintile portfolios formed using nine option-based measures of stock mispricing. Panel A reports returns and alphas of portfolios formed on IPD and implied lending fees, the two measures that are based on differences between actual and implied stock prices. Both of these measures successfully predict stock returns in each of the three months following portfolio formation. A long-short strategy of buying the quintile of stocks with the highest IPD, that is the greatest differences between implied and actual stock prices, and selling the quintile of stocks with the lowest IPD, produces four-factor alphas of 77 basis points, 73 basis points, and 43 basis points in the three months after portfolio formation. Similarly, the long-short strategy of buying the quintile of stocks with low implied lending fees and selling the portfolio with high implied lending fees produces four-factor alphas of 77 basis points, 58 basis points and 53 basis points for the three months following portfolio formation. These alphas, like the alphas from the IPD long-short strategy are all statistically significant at any conventional level. It is significant that investors could wait one or two months after the calculation of IPD or implied fees and still earn abnormal returns. This suggests that the returns are not an artifact of microstructure noise. They could not, for example, be a result of stale trade prices or bid-ask bounce.

The ability of these measures to predict stock returns appears to come almost entirely from the short-side. In Panel A, the portfolio with the lowest IPD, that is the lowest implied prices relative to actual prices, has an alpha of -62 basis points with a t-statistic of -4.86 for month t+1. In contrast, the portfolio with the highest IPD, or greatest implied price relative to actual prices, has an alpha of 16 basis points with a t-statistic of 1.53. Similarly, the portfolio of stocks with high implied lending fees earns abnormal returns of -65 basis points with a t-statistic of -6.65 for the month after portfolio formation. The quintile of stocks with low implied fees earns abnormal returns of 12 basis points with a t-statistic of 2.23. Results for months t+2 and t+3 are similar for portfolios based on both IPD and implied lending fees. In both months t+2 and t+3, significant negative abnormal returns are earned in the bearish portfolio, but none of the other portfolios have significantly positive alphas.

These results suggest that for equal-weighted portfolios, which consist mainly of small stocks, the costs of short-selling and short-sale restrictions are behind the ability of option-based measures to predict stock returns. In each case, negative alphas, which provide profit opportunities for short-sellers, are larger and more significant than positive alphas. These portfolios are equal-weighted, so small stocks, which may be difficult to short, make up a significant part of the portfolios. It seems likely that the high and low portfolios in particular may be heavily weighted with small stocks.

Panel B reports results for portfolios formed using option based measures of mispricing derived from implied volatilities. Sorts based on Skewness, ΔPVOL, and CW all produce portfolios that provide significant abnormal returns from long-short strategies in one or more months following portfolio formation. The abnormal returns produced by skewness, ΔCVOL, and ΔPVOL are small relative to those produced by measures based on differences in implied and actual stock prices. Long-short alphas from portfolios based on CW are of similar magnitude to the alphas portfolios produced by IPD and implied lending fees. The other implied volatility measures generate smaller long-short portfolio alphas.

The abnormal returns earned by portfolios sorted on these measures also come from the short side. For example, the low CW portfolio, that is the portfolio where implied volatilities of calls are low relative to the implied volatilities of puts, earns abnormal returns of -61 basis points, -53 basis points and -42 basis points in the three months following portfolio formation. Each of these is significantly less than zero at the 1% level. In contrast, the abnormal returns of the high CW portfolio are less than 14 basis points in each of the three succeeding months and never significant. Similar results are obtained from portfolios based on skewness and ΔPVOL.

Panel C provides results for portfolios formed using options order imbalance (OOI), Pan Poteshman (PP) and the log ratio of option to stock volume (O/S). Each of these measures is based on trading volume. The results for OOI and PP are weak. A long-short strategy produces abnormal returns for OOI but only for the first month following portfolio formation. The long-short strategy fails to produce significant abnormal returns at all for PP. This is not entirely surprising though as the PP measure was originally used to predict returns over shorter intervals. For O/S, a long-short strategy produces significant abnormal returns in each month. The returns again come primarily from the short-side. Again, for all these measures, short-sale restrictions appear to be the source of returns to option based strategies.

We also calculate average returns and alphas for the equal-weighted quintile portfolios for the two five year periods 2003-2008 and 2009-2013. Results (not shown) are very similar for the two subperiods. In both periods, most of these option-based measures are able to find overpriced stocks that underperform by statistically significant amounts. Quintile portfolios of underpriced stocks may have positive alphas, but they are generally insignificant in both periods. SEC Rule 10b-21, which cracked down on naked shorting and failures to deliver, became effective in mid-October 2008, very close to the end of the first subperiod. Our finding that option-based measures of mispricing had similar predictive power in both subperiods suggests that Rule 10b-21 had little impact on bearish investors' decisions whether to trade stock or options.

All of these measures of stock mispricing are taken from options, so it might seem that they contain the same information. We find, though, that portfolio sortings across measures have surprisingly low correlations (see Table 8 in the text). Hence it seems possible that double-sorts on these measures may produce larger returns.

In Panel A of Table A2 we first sort stocks into quintiles by IPD, and then sort each IPD quintile into quintiles by O/S. In Panel B, we sort first on IPD, and then on skewness. In Panel C, we first sort stocks by implied borrowing fees and then by skewness. These double sorts do produce portfolios of stocks with very large negative abnormal returns. In Panel A, the low IPD/High O/S portfolio earn an average alpha of -1.0192 in the first month after portfolio formation. The low IPD/high skewness portfolio in Panel B earns an abnormal return of -1.3620% for month t+1. Finally, the high implied fee/high skewness portfolio in Panel C earns an alpha of -0.9038 in the month following portfolio formation. As Table 11 in the text shows, however, the portfolios that appear to generate large returns from shortselling are very heavily weighted with hard-to-borrow stocks. In contrast, none of the double sorts yields a portfolio with especially large positive alphas.

Table A1.

Returns for equal-weighted quintiles of stocks sorted on various option-based measures of mispricing. Each month over 2004-2013, stocks are sorted into quintiles based on option based measures of stock mispricing. IPD is the average percentage difference between implied and actual stock prices. Implied borrowing fees is the stock borrowing fee implied by violations of put-call parity. CW is the difference between implied volatilities of calls and puts. Skewness is the difference in implied volatilities of a put with a delta of 0.2 and a call with a delta of 0.5. ΔPVOL is the monthly change in implied volatilities for 30 day puts with deltas of -0.5. ΔCVOL is the change analogous change in call implied volatilities. PP is the ratio of put buy volume that opens positions to the sum of put and call buy volume. OOI is the difference between synthetic positive and negative options volume. O/S is the natural logarithm of the ratio of stock and options volume. The Fama-French-Carhart four factor model is used to calculate α's. Newey-West adjusted standard errors with three lags are used. Returns and α's are in percentages.

Panel A. Measures based on the difference between implied and actual stock prices

Stocks sorted on IPD. The implied price difference is calculated using option trade prices.

Port.	R_{t+1}	α_{t+1}	T Stat.	R_{t+2}	α_{t+2}	T Stat.	R_{t+3}	α_{t+3}	T Stat.
Low	0.2639	-0.6168	-4.86	0.3078	-0.6199	-4.74	0.5320	-0.3921	-2.75
2	0.7817	0.0174	0.24	0.7619	-0.0459	-0.69	0.7586	-0.0637	-0.92
3	0.7289	0.0032	0.04	0.7647	-0.0049	-0.06	0.7220	-0.0391	-0.44
4	0.7757	0.0374	0.40	0.8700	0.0897	0.89	0.8493	0.0740	0.78
High	1.0051	0.1566	1.53	0.9691	0.1068	1.02	0.8967	0.0356	0.39
H-L	0.7412	0.7734	5.91	0.6613	0.7268	5.16	0.3647	0.4277	3.05

Stocks sorted on implied stock borrowing fees

Port.	R_{t+1}	α_{t+1}	T Stat.	R_{t+2}	α_{t+2}	T Stat.	R_{t+3}	α_{t+3}	T Stat.
Low	0.8509	0.1223	2.23	0.8169	0.0441	0.72	0.8381	0.0702	0.94
2	0.9148	0.2006	2.70	0.8479	0.0962	1.15	0.8708	0.1260	1.63
3	0.8063	0.0773	1.07	0.8597	0.0912	1.07	0.8212	0.0642	0.79
4	0.7201	-0.0453	-0.55	0.8442	0.0283	0.37	0.8789	0.0638	0.67
High	0.1994	-0.6524	-6.65	0.3540	-0.5336	-5.58	0.4271	-0.4609	-3.95
H-L	-0.6515	-0.7747	-7.68	-0.4629	-0.5777	-5.47	-0.4109	-0.5310	-4.11

Panel B. Measures based on implied volatilities

Sort based on Cremers Weinbaum (CW) measure.

Port.	R_{t+1}	α_{t+1}	T Stat.	R_{t+2}	α_{t+2}	T Stat.	R_{t+3}	α_{t+3}	T Stat.
Low	0.2523	-0.6053	-4.42	0.3814	-0.5282	-4.42	0.4894	-0.4203	-3.28
2	0.7937	0.0274	0.39	0.7317	-0.0683	-0.89	0.7755	-0.0203	-0.26
3	0.8150	0.0898	1.30	0.9612	0.2084	2.95	0.8913	0.1290	1.84
4	0.9219	0.1815	3.06	0.8957	0.1158	1.67	0.8884	0.1110	1.49
High	0.9992	0.1120	0.90	1.0526	0.1359	0.89	1.0234	0.1322	0.95
H-L	0.7469	0.7173	5.48	0.6712	0.6641	4.24	0.5340	0.5526	3.78

Sort based on skewness.

Port.	R_{t+1}	α_{t+1}	T Stat.	R_{t+2}	α_{t+2}	T Stat.	R_{t+3}	α_{t+3}	T Stat.
Low	0.9702	0.0926	0.64	0.9637	0.0566	0.39	0.9982	0.1204	0.88
2	0.8790	0.1596	1.75	0.8551	0.0845	1.03	0.8678	0.0893	1.05
3	0.7277	-0.0388	-0.48	0.8220	0.0187	0.20	0.7560	-0.0404	-0.49
4	0.6271	-0.1814	-2.53	0.7570	-0.0988	-1.57	0.7907	-0.0394	-0.54
High	0.5275	-0.2549	-2.69	0.5454	-0.2660	-2.72	0.5579	-0.2819	-2.65
H-L	-0.4427	-0.3475	-1.89	-0.4184	-0.3226	-1.85	-0.4403	-0.4026	-2.31

Sort based on change in implied volatilities of calls (ΔCVOL).

Port.	R_{t+1}	α_{t+1}	T Stat.	R_{t+2}	α_{t+2}	T Stat.	R_{t+3}	α_{t+3}	T Stat.
Low	0.5308	-0.2933	-2.39	0.7063	-0.1989	-1.62	0.8480	-0.0466	-0.46
2	0.8168	0.0847	1.25	0.8551	0.0573	0.75	0.8266	0.0129	0.14
3	0.8072	0.0758	0.92	0.8975	0.1177	1.44	0.9306	0.1266	1.47
4	0.8163	0.0475	0.68	0.8421	0.0525	0.63	0.8450	0.0119	0.14
High	0.7767	-0.1264	-1.18	0.7310	-0.1736	-1.81	0.7502	-0.1617	-1.33
H-L	0.2459	0.1669	1.22	0.0246	0.0253	0.18	-0.0978	-0.1151	-0.78

Sort based on change in implied volatilities of puts (ΔPVOL).

Port.	R_{t+1}	α_{t+1}	T Stat.	R_{t+2}	α_{t+2}	T Stat.	R_{t+3}	α_{t+3}	T Stat.
Low	0.8012	-0.0163	-0.13	0.6605	-0.2404	-2.07	0.8703	-0.0372	-0.41
2	0.7859	0.0481	0.66	0.9083	0.1009	1.29	0.9015	0.0942	1.10
3	0.8253	0.1066	1.24	0.9350	0.1603	1.87	0.9102	0.1073	1.33
4	0.7812	0.0032	0.05	0.8459	0.0418	0.50	0.7959	-0.0330	-0.41
High	0.5544	-0.3530	-3.43	0.6823	-0.2077	-2.23	0.7224	-0.1886	-1.56
H-L	-0.2469	-0.3366	-2.55	0.0218	0.0327	0.25	-0.1479	-0.1514	-1.19

Panel C. Sorts based on option trades and volume

Sorted on Options Order Imbalance

Port.	R_{t+1}	α_{t+1}	T Stat.	R_{t+2}	α_{t+2}	T Stat.	R_{t+3}	α_{t+3}	T Stat.
Low	0.3806	-0.4407	-4.88	0.5994	-0.2514	-2.67	0.7145	-0.1728	-2.21
2	0.8083	0.0661	0.93	0.8439	0.0644	1.01	0.8324	0.0205	0.20
3	1.0514	0.2439	2.12	1.0287	0.1976	1.92	0.9180	0.0542	0.69
4	0.9208	0.1215	1.24	1.0303	0.1742	1.91	1.0336	0.1419	1.28
High	0.9194	0.0189	0.17	0.7201	-0.2181	-1.81	0.8298	-0.1157	-1.01
H-L	0.5387	0.4596	3.83	0.1206	0.0333	0.30	0.1153	0.0571	0.48

Sorted on Pan Poteshman

Port.	R_{t+1}	α_{t+1}	T Stat.	R_{t+2}	α_{t+2}	T Stat.	R_{t+3}	α_{t+3}	T Stat.
Low	0.6282	-0.2846	-1.69	0.5976	-0.3576	-2.44	0.6183	-0.3330	-2.33
2	0.7396	-0.0450	-.038	0.7539	-0.0819	-0.67	0.8445	-0.0253	-0.25
3	0.7670	0.0021	0.03	0.8030	-0.0274	-0.27	0.8138	-0.0296	-0.34
4	0.6597	-0.1063	-1.06	0.7392	-0.0528	-0.53	0.8005	-0.0499	-0.56
High	0.6852	-0.0936	-1.00	0.7100	-0.0921	-0.89	0.7971	-0.0346	-0.41
H-L	0.0569	0.1911	0.89	0.1124	0.2655	1.26	0.1788	0.2985	1.85

Sorted on O/S

Port.	R_{t+1}	α_{t+1}	T Stat.	R_{t+2}	α_{t+2}	T Stat.	R_{t+3}	α_{t+3}	T Stat.
Low	0.8785	0.1142	1.55	0.9473	0.1476	2.02	0.9143	0.1145	1.86
2	0.8716	0.0706	0.92	0.8259	-0.0206	-0.31	0.8316	-0.0110	-0.14
3	0.7821	-0.0026	-0.03	0.8961	0.0688	0.85	0.8340	0.0191	0.31
4	0.6911	-0.1187	-1.31	0.6799	-0.1465	-1.63	0.7673	-0.0485	-0.52
High	0.4044	-0.3728	-4.25	0.4706	-0.3627	-3.95	0.4797	-0.3615	-3.64
H-L	-0.4741	-0.4870	-4.18	-0.4768	-0.5103	-4.15	-0.4346	-0.4760	-4.53

Table A2. Panel A. Portfolios formed from double sorts of stocks on IPD and O/S.

All stocks, equal-weighted portfolios.

	Low O/S	2	3	4	High O/S	High - Low
Low IPD	-0.0032	-0.3225	-0.6042	-0.8547	-1.0192	-1.0159
	(-0.02)	(-1.66)	(-3.45)	(-4.29)	(-4.31)	(-3.56)
2	0.3213	0.0379	0.1625	-0.0600	-0.3714	-0.6928
	(2.06)	(0.28)	(1.14)	(-0.45)	(-2.18)	(-2.81)
3	0.2734	0.0392	-0.0615	-0.0246	-0.2433	-0.5166
	(2.41)	(0.32)	(-0.45)	(-0.17)	(-1.72)	(-2.77)
4	-0.0235	-0.0183	0.1824	0.0744	-0.2594	-0.2359
	(-0.21)	(-0.13)	(1.22)	(0.65)	(-1.59)	(-1.47)
High IPD	-0.1633	0.0669	0.2611	0.1570	0.0865	0.2498
	(-0.99)	(0.49)	(1.57)	(0.90)	(0.59)	(1.35)
High - Low	-0.1600	0.3894	0.8653	1.0117	1.1057	
	(-0.67)	(1.83)	(3.53)	(3.75)	(3.89)	

Panel B. Portfolios formed from double sorts of stocks on IPD and Skewness.
All stocks, equal-weighted portfolios.

	Low Skew	2	3	4	High Skew	High - Low
Low IPD	0.0450	-0.0109	-0.4105	-1.0919	-1.3169	-1.3620
	(0.14)	(-0.06)	(-2.20)	(-5.57)	(-5.08)	(-3.48)
2	0.1229	0.1622	0.0464	-0.0995	-0.0311	-0.1540
	(0.67)	(1.33)	(-0.31)	(-0.72)	(-0.18)	(-0.59)
3	-0.0077	0.0483	-0.0180	0.1518	-0.2061	-0.1984
	(-0.05)	(0.38)	(-0.14)	(0.96)	(-1.65)	(-0.98)
4	0.1488	-0.0195	-0.0537	-0.0260	-0.0573	-0.2061
	(0.95)	(-0.12)	(-0.38)	(-0.18)	(-0.40)	(-0.98)
High IPD	-0.1243	0.3437	0.1080	-0.1192	0.2228	0.3470
	(-0.53)	(2.03)	(0.84)	(-0.82)	(1.32)	(1.48)
High - Low	-0.1693	0.3546	0.5185	0.9727	1.5397	
	(-0.61)	(1.66)	(2.24)	(4.15)	(4.52)	

Panel C. Portfolios formed from double sorts of stocks on implied borrowing fees and skewness. All stocks, equal-weighted portfolios.

	Low Skew	2	3	4	High Skew	High - Low
Low Imp.	-0.1743	0.1630	0.1755	0.2693	0.1886	0.3629
Fee	(-1.17)	(1.52)	(1.59)	(2.42)	(1.44)	(1.69)
2	0.1946	0.1531	0.2036	0.2062	0.2276	0.0329
	(1.37)	(1.25)	(2.00)	(1.49)	(1.59)	(0.16)
3	0.2358	0.0892	-0.0740	0.2263	-0.1120	-0.3478
	(1.65)	(0.69)	(-0.60)	(1.59)	(-0.85)	(-1.72)
4	0.0007	-0.0493	-0.0765	-0.1348	0.0072	0.0065
	(0.00)	(-0.34)	(-0.55)	(-1.29)	(0.06)	(0.03)
High Imp.	-0.2159	-0.4013	-0.9707	-0.7615	-0.9038	-0.6879
Fee	(-0.99)	(-2.52)	(-6.73)	(-4.40)	(-4.82)	(-2.45)
High - Low	-0.0416	-0.5643	-1.1462	-1.0308	-1.0924	
	(-0.16)	(-3.23)	(-6.99)	(-5.13)	(5.82)	