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Eli Ofek
Matthew Richardson
Robert F. Whitelaw

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ABSTRACT

In this paper, we investigate empirically the well-known put-call parity no-arbitrage relation in the presence of short sale restrictions. We use a new and comprehensive sample of options on individual stocks in combination with a measure of the cost and difficulty of short selling, specifically the spread between the rate a short-seller earns on the proceeds from the sale relative to the standard rate (the rebate rate spread). We find that violations of put-call parity are asymmetric in the direction of short sales constraints, their magnitudes are strongly related to the rebate rate spread, and they are maintained even in the presence of transactions costs both in the options and equity lending market. These violations appear to be related to both the maturity of the option and the level of valuations in the stock market, consistent with a behavioral finance theory that relies on over-optimistic investors in the stock market and segmentation between the stock and options markets. Moreover, the extent of violations of put-call parity and the rebate rate spread for individual stocks are significant predictors of future stock returns. For example, cumulative abnormal returns, net of borrowing costs, over a 2½-year sample period can exceed 65%.

Eli Ofek
NYU, Stern School of Business
44 W. 4th St.
New York, NY 10012

Matthew Richardson
NYU, Stern School of Business
44 W. 4th St.
New York, NY 10012
and NBER
mrichardson@stern.nyu.edu

Robert F. Whitelaw
NYU, Stern School of Business
44 W. 4th St.
New York, NY 10012
and NBER
rwhitela@stern.nyu.edu

I. Introduction

The concept of no arbitrage is at the core of our beliefs about finance theory. In particular, two assets with the same payoffs should have the same price. If this restriction is violated, then at least two conditions must be met. First, there must be some limits to arbitrage that prevent the convergence of these two prices (e.g., Shleifer (2000) and Barberis and Thaler (2002)). Second, there must exist a reason why these assets have diverging prices in the first place. The goal of our paper is to analyze the impact of these two conditions in an obvious no-arbitrage framework.

There is perhaps no better example in finance than the case of redundant assets, for example, stocks and options on those stocks. One of the most commonly cited no-arbitrage relations using stocks and options is that of put-call parity. The put-call parity condition assumes that investors can short the underlying securities. If short sales are not allowed, then this no-arbitrage relation can breakdown. Of course, even without short sales, the condition does not necessarily fail. Suppose that the stock is priced too high on a relative basis. Then one could form a portfolio by buying a call, writing an equivalent put, and owning a bond; the return on this portfolio would exceed the return on the stock in all possible circumstances. This is a difficult phenomenon to explain in "rational" equilibrium asset pricing models.

There is a considerable, and growing, literature that looks at the impact of short sales restrictions on the equity market. (See, for example, Lintner (1969), Miller (1977), Harrison and Kreps (1978), Jarrow (1981), Figlewski (1981), Chen, Hong and Stein (2000), D'Avolio (2001), Geczy, Musto and Reed (2001), Mitchell, Pulvino and Stafford (2001), Ofek and Richardson (2001), Jones and Lamont (2001), and Duffie, Garleanu and Pedersen (2002), among others.) However, there has been much less attention paid to understanding the direct links between short sales and the options market (Figlewski and Webb (1993), Danielson and Sorescu (2001) and Lamont and Thaler (2000) are notable exceptions). Of particular interest to this paper, Lamont and Thaler (2000) document severe violations of put-call parity for a small sample of three stocks that have gone through an equity carve-out and the parent sells for less than its ownership stake in the carve-out. Lamont and Thaler (2000) view this evidence as consistent with high costs of shorting these stocks.

This paper provides a comprehensive analysis of put-call parity in the context of short sales restrictions. We employ two novel databases from which we construct matched pairs of call and put options and stock prices across the universe of equities, as well as a direct measure of the shorting costs of each of these stocks, namely their rebate rate.[1] We report several interesting results. First, consistent with the theory of limited arbitrage, we find that the violations of the put-call parity no-arbitrage restriction are asymmetric in the direction of short sales restrictions.[2] These violations still persist even after incorporating shorting costs and/or extreme assumptions about transactions costs (i.e., all options transactions take place at ask and bid prices). For example, after shorting costs, 13.63% of stock prices still exceed the upper bound from the options market while only 4.36% are below the lower bound. Moreover, the mean difference between the option-implied stock price and the actual stock price for these violations is 2.71%.

Second, under the assumption that the rebate rate maps one-to-one with the difficulty of shorting, we find a strong general relation between violations of no arbitrage and short sales restrictions. In particular, both the probability and magnitude of the violations can be linked directly to the magnitude of the rebate rate, or, in other words, the degree of specialness of the stock. In a regression context, a one standard deviation decrease in the rebate rate spread implies a 0.67% increase in the deviation between the prices in the stock and options markets. This result is robust to other measures such as liquidity in either the equity or options markets, stock and option characteristics and transactions costs.

The above results suggest that the relative prices of similar assets (i.e., ones with identical payoffs) can deviate from each other when arbitrage is not possible. If we take the view that these deviations rule out our most standard asset pricing models, then what possible explanations exist? If markets are sufficiently incomplete, and there is diversity

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[1] In particular, when an investor shorts a stock, he (i.e., the borrower) must place a cash deposit equal to the proceeds of the shorted stock. That deposit carries an interest rate referred to as the rebate rate.

[2] Related phenomena exist in other markets. For example, short-sellers of gold must pay a fee called the lease rate in order to borrow gold. This short-selling cost enters the no-arbitrage relation between forward and spot prices of gold as a convenience yield (see McDonald and Shimko (1998)). Longstaff (1995)

across agents, then it may be the case that these securities offer benefits beyond their risk-return profiles (see, for example, Detemple and Jorion (1990), Detemple and Selden (1991), Detemple and Murthy (1977), and Basak and Croitoru (2000)). Alternatively, if markets are segmented such that the marginal investors across these markets are different, it is possible that prices can differ. Of course, in the absence of some friction preventing trading in both markets, this segmentation will not be rational.

Third, we provide evidence on this latter explanation by taking a simple framework in which the stock and options markets are segmented. Under particular assumptions, this allows us to interpret the differences between a stock's market value and its value implied by the options market. Assuming that the equity markets are "less rational" than the options markets, and using data on multiple option pairs, we are able to relate the magnitude of the mispricing to specific information about the ability to short sell (e.g., the rebate rate) and predicted maturity effects. For example, we find that put-call parity violations are related to both the maturity of the options and potential mispricing levels of the stock. We also evaluate the model's ability to forecast future movements in stock returns. Filtering on rebate rate spreads and measures of mispricing from the options market yields average returns on the stock over the life of the option that are as low as -12.6%. In addition, cumulative abnormal returns, net of borrowing costs, on portfolios that are long the industry and short stocks chosen using similar filters are as high as 65% over our sample period.

This paper is organized as follows. In Section II, we review the basics of put-call parity and the lending market, and then describe the characteristics of the data used in the study. Section III presents the main empirical results on the violations of put-call parity and their link to short sale restrictions. In Section IV, we apply our analysis to imputing the overvaluation of stocks using evidence from the options market. Section V makes some concluding remarks.

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examines transaction costs in the market for index options and shows that these costs can increase the implied cost of the index in the options market relative to the spot market.

II. Preliminaries

A. Put-Call Parity

Under the condition of no arbitrage, it is well known that, for European options on non-dividend paying stocks, put-call parity holds:

$$S = PV(K) + C - P$$

where S is the stock price, PV(K) is the present value of the strike price, and C and P are the call and put prices respectively on options with strike price K and the same maturity T. For American options, Merton (1973) shows that the puts will be more valuable because at every point in time there is a positive probability of early exercise. That is,

$$S \geq PV(K) + C - P \tag{1}$$

There are essentially two strands of the literature that investigate equation (1) above. The first group of papers contains a series of empirical investigations (e.g., Gould and Galai (1974), Klemkosky and Resnick (1979), Bodurtha and Courtadon (1986), Nisbet (1992), Kamara and Miller (1995), and Lamont and Thaler (2000)). The evidence from this literature is mixed but for the most part finds that put-call parity holds as described by equation (1).

For example, Gould and Galai (1974) show that, in the early days of the options market, the transactions costs would have to be large to explain the put-call parity violations. In contrast, Klemkosky and Resnick (1979) extend the analysis to incorporate both dividend-paying stocks and the possibility of early exercise and show that for the most part the evidence is consistent with put-call parity and market efficiency. Interestingly, the few violations they report imply asymmetric violations opposite to the ones reported in this paper, namely "overpriced" call prices. While they do not try to explain these findings, the universe of options looked at in their paper is a much smaller set than later investigations. Nisbet (1992) performs a comprehensive analysis of the London Traded Options Market for a six-month period in 1988. She also looks at dividend paying stocks but adds direct estimates of transactions costs to the analysis and generally finds that apparent violations cannot be exploited. Later studies, such as Kamara and Miller (1995), tend to focus on index options as the options are liquid and of the European type. They find less instances of violations than previous studies though the studies are not directly comparable due to the underlying being individual equities versus indices. The paper closest to ours in spirit is that of Lamont and Thaler (2000) who document large violations of put-call parity for a sample of three stocks that (i) have gone through an equity carve-out, and (ii) the parent sells for less than its ownership stake in the carve-out. The analysis in this paper looks at a much wider universe of stocks and their underlying options.

The second strand of the literature is concerned with analytical valuation formulas for American put options in which explicit values are given for the early exercise premium (e.g., Johnson (1983), Geske and Johnson (1984), Ho, Subrahmanyam and Stapleton (1994) and Unni and Yadav (1999)). Specifically, equation (1) can be rewritten

$$S = PV(K) + C - P + EEP \tag{2}$$

where EEP is the early exercise premium on the American put option.

At least two conditions must be met for equation (2) to fail. First, there must be some limits on arbitrage.[3] The most commonly cited limit is short sale restrictions. Without short sales, if the stock price drifts above its implied price in the options market, then there does not exist an arbitrage that will automatically lead to convergence of the two values. There is a large, and growing, literature in finance that documents both the theoretical and empirical importance of short sales restrictions.[4]

Second, it must be possible that the values given by equation (2) can drift apart. That is, why would an investor purchase shares for $S when he/she could duplicate the payoff of the stock using the bond market and call-put option pairs? Perhaps, it is too difficult or costly to replicate shares in the options market (e.g., transactions costs), or there is some hidden value in owning shares (e.g., Duffie, Garleanu and Pedersen (2001)), or, alternatively, options provide some additional value in terms of risk management due to markets being incomplete (e.g., Detemple and Selden (1991)).

The most popular explanation though lies at the roots of behavioral finance. Behavioral finance argues that prices can deviate from fundamental values because a significant part of the investor class is irrational. These irrational investors look to other

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[3] Of course, equation (2) is no longer strictly an arbitrage relation as the value of the early exercise premium is incorporated directly.

information, e.g., market sentiment, or are driven by psychological (rather than financial) motivations. This class of investors has the potential to move asset prices, and, in the presence of limited arbitrage, there is no immediate mechanism for correcting these mispricings (see, for example, Shleifer (2000)). In the context of equation (2), if the equity and options markets are segmented, i.e., have different investors, then mispricings in the equity market do not necessarily carry through to the options market (see Lamont and Thaler (2000)). In other words, irrational investors do not use the options market.

In particular, as long as the investors in options are different than those in the equity market, and these investors believe there is a positive probability that asset prices will revert back to their fundamental price by the time the options expire, there can be a substantial difference between the market asset price and the implied asset price from the options market. Of course, these differences can only persist in the presence of limited arbitrage, whether that is due to transactions costs or, more directly, short sales restrictions. An interesting feature generated by the fixed expiration of the option is that, in a world of mean reversion to fundamental values, the maturity of the option can be an important determinant of the level of mispricing in equation (2).

In this paper, we investigate violations of equation (2) and relate it to the conditions described above, namely (i) limited arbitrage via either short sales restrictions or transactions costs, and (ii) potential periods of mispricing between equities and their corresponding options. This latter condition is evaluated by looking at both expected maturity effects in a mispriced world, potential structural shifts in mispricing, and the forecastability of future returns.

B. The Lending Market

There has been recent interest in the lending market for stocks. For example, D'Avolio (2001) and Geczy, Musto and Reed (2001) provide a detailed description and analysis of this market. Beyond the papers described in footnote 4 that show the potential theoretical effects of short sales restrictions and document empirical facts strongly

[4] See, for example, Lintner (1969), Miller (1977), Jarrow (1981), Figlewski (1981), Chen, Hong and Stein (2000), D'Avolio (2001), Geczy, Musto and Reed (2001), Ofek and Richardson (2001), Jones and Lamont

relating short sales restrictions to stock prices, D'Avolio (2001) and Geczy, Musto and Reed (2001) present evidence that short sales restrictions exist and are not uncommon.

There are essentially two reasons why short sales restrictions exist, namely investors either are unwilling to sell stock short or find it too difficult to do so. In the former case, Chen, Hong and Stein (2000) provide a detailed account of why investors may be unwilling to short stock. In particular, they focus on an important group of investors, i.e., mutual funds, and argue that, though restrictions under the Investment Company Act of 1940 are no longer binding, mutual funds still abide by that act. In fact, Almazan, Brown, Carlson, and Chapman (2001) shows only a small fraction of mutual funds short stocks, and provide evidence of greater mispricings when mutual funds are absent from the market.

In the latter case, there are both theoretical reasons and supporting empirical evidence that suggests it is difficult to short stocks on a large scale. First, in order to short a stock, the investor must be able to borrow it. In general, there are only a limited number of shares available for trading (i.e., a stock's float is finite),[5] and someone (i.e., an institution or individual) would have to be willing to lend the shares. For whatever reason, individuals tend to lend shares less than institutions do. Second, there is no guarantee that the short position will not get called either through the lender demanding the stock back or a margin call. In this case, there is no guarantee that the investor will be able to re-short the stock.

When an investor shorts a stock, he/she places a cash deposit equal to the proceeds of the shorted stock. That deposit carries an interest rate referred to as the rebate rate. If shorting is easy, the rebate rate closely reflects the prevailing market rate. However, when supply is tight, the rebate rate tends to be lower. This lower rate reflects compensation to the lender of the stock at the expense of the borrower, and thus can provide a mechanism for evening out demand and supply in the market. One way to measure the difficulty in short selling is to compare the rebate rate on a stock against the corresponding "cold" rate, i.e., the standard rebate rate on stocks that day. Since there is

(2001), and Duffie, Garleanu and Pedersen (2002) to name a few.

[5] For example, there are only a limited number of shares issued by corporations. Moreover, insiders may be reluctant, or prevented, from selling. In the extreme case, for six months after an IPO, most of the shares have lockup restrictions.

limited demand for short selling the majority of stocks, empirically this “cold” rate corresponds to the median rebate rate.

There are two ways in which we view the rebate rate spread in this paper. First, it can be used as the actual cost of borrowing a stock, and thus the rate can be employed in equation (2) in that context (e.g., Mitchell, Pulvino and Stafford (2001) and D’Avolio (2001)). Second, as pointed out by Geczy, Musto and Reed (2001) and Ofek and Richardson (2002), the lending market is not a typical well-functioning, competitive market. Thus, it may not be appropriate to treat rebate rates as competitive lending rates, and, instead, we use the rebate rate as a signal of the difficulty of shorting, i.e., the degree to which short sales restrictions are binding.

Alternatively, if investors are limited by how many shares they can short, there are other ways to bet against the stock. For example, one could imagine setting up a synthetic short position using the options market. Figlewski and Webb (1993) and Lamont and Thaler (2000) look at this case empirically. In the context of our discussion in Section II.A, we might expect to see violations of put-call parity as the standard no-arbitrage condition can be violated due to short sale restrictions and overvaluation of stocks. In this case, there would be excess demand for put options relative to call options, leaving a significant spread between the prices. As an extreme example, Lamont and Thaler (2000) show that, in the Palm/3Com case, the synthetic short for Palm (i.e., its implied value from options) was substantially lower than the traded price of Palm (approximately 30% less during the first few weeks). This is consistent with the equity prices reflecting one set of beliefs and the options market reflecting another.

C. Data

This paper looks at put-call parity in the options market in conjunction with short sales restrictions as measured by the rebate rate. We employ two unique data sets over the sample period July 1999 to November 2001. Specifically, we look at daily data for 118 separate dates during this period that are approximately 5 business days apart.

The first dataset comes from OptionMetrics, who provide end-of-day bid and ask quotes, open interest, and volume on every call and put option on an individual stock traded on a U.S. exchange (often more than 3 million option observations per month). Along with the options data are the corresponding stock prices, dividends and splits, as well as option-specific data such as implied volatilities, interest rates, maturities, and exercise prices (see the appendix for details).

The second dataset includes the rebate rate for almost every stock in our options sample. In particular, a financial institution, and one of the largest dealer-brokers, provided us with its proprietary rebate rates for the universe of stocks on the aforementioned selected dates. The rebate rate quoted represents an overnight rate and thus includes no term contracts, which are also possible in the lending market. The existence of a rebate rate quote is not an implicit guarantee that the financial institution will be able to locate shares of the stock for borrowing. It is simply the rate that will apply if the stock can be located. Moreover, the rebate rate quote may not be the same as that quoted by another institution, although these rates are likely to be highly correlated. For each day, we calculate the short selling cost as the deviation of the rebate rate on a particular stock from the "cold" rate for the day, i.e., the standard rebate rate on the majority of stocks. We denote this cost as the rebate rate spread throughout the paper. Obviously, this spread will be zero for the majority of firms.

There is one potentially important measurement issue with respect to the rebate rates. It appears that not all the quotes are synchronous. Therefore, if interest rates and the "cold" rate move during the day, stale rebate rates may appear to deviate from the "cold" rate even though they did not do so at the time of the original quote. This phenomenon is most obvious in small positive rebate rate spreads, which we set to zero. When the rebate rate spread is small and negative, there is no obvious way to determine if it is truly negative of if it is the result of nonsynchronicity. As a result, we do not adjust these spreads, and there is likely to be some measurement error in rebate rate spreads, especially at low absolute magnitudes.

Table 1A describes our entire sample of option pairs, i.e., puts and calls with the same exercise price and maturity, after we apply a set of preliminary filters. These filters are described in detail in the appendix, but the primary requirements are that the stock be non-dividend paying and that both the put and call have positive open interest. Over the sample period, this sample includes a total of 1,359,461 option pairs. These pairs span

118 dates, with approximately 1100 firms per date and 10 option pairs per firm (an average of 2.5 different maturities and 4.3 different strike prices per maturity). The median and mean maturity of the options pairs are 115 and 162 days, respectively. The open interest on the call options tends to be larger than on the put options, with the mean and medians being 711 and 133 contracts respectively versus 481 and 63. Note, however, that the daily volume can be quite low, especially for the put options. In particular, the mean and median volume for the call and puts respectively are 32 and 0 versus 16 and 0, respectively. Of course, even though over half the sample of options on any day do not trade, this does not mean that the bid and ask quotes do not represent accurate prices at which the options can be bought and sold. As a robustness check, we duplicated the analysis that follows only using options that had positive trading volume. While the sample sizes are much smaller, the results are qualitatively the same.

For the analysis, we further wish to restrict our sample to homogenous sets of option pairs. Therefore, we break up the sample into three maturity groups: (i) short (i.e., 30 to 90 days), (ii) intermediate (i.e., 91 to 182 days), and (iii) long (i.e., 183-365 days). Furthermore, we focus on options that are close to at-the-money (i.e., $-0.1 < \ln(S/K) < 0.1$) and apply a second set of filters to eliminate bad data (see the appendix). The majority of the analysis looks at the at-the-money, intermediate maturity option pairs. If there are multiple option pairs per stock on a given day that match the relevant maturity and moneyness criteria, then we restrict ourselves to the option pairs that are closest to the middle of the range. This provides us with a maximum of one option pair per stock per date.

Table 1B provides a summary of the data for the at-the-money, intermediate maturity option pairs. The sample contains 80,614 pairs of options with median and mean expirations of slightly over 130 days. These observations span 1734 different stocks, with an average of 683 stocks per date. Compared to the larger sample, the open interest and volume for the calls and puts are of a similar magnitude. Of some interest to the analysis of put-call parity with transactions costs, the mean and median values of the bid-ask spread on calls and puts range from 7.4% to 9.2%. Thus, in the extreme case in which transactions only take place at ask and bid prices, these costs may be especially relevant.

Table 1B illustrates three other important features of the data. First, the implied volatilities of the stocks are quite high by historical standards, that is, almost 75% on average. Note that these implied volatilities are calculated using the Black-Scholes pricing model for call options assuming no dividends. Second, the early exercise premium for puts is relatively low, representing less than 1% of the value of the option on average and only slightly more than 0.1% of the stock price. We use the method of Ho, Stapleton and Subrahmanyam (1994) to estimate this premium for each put option on each date. All the put-call parity conditions are then adjusted for this estimate as in equation (2). Finally, the mean and median annualized rebate rate spreads, conditional on being special (i.e., the rebate rate spread being negative), are –1.57% and –0.46%, respectively. The interpretation of these values in terms of both the actual costs of shorting, and more generally as an indicator of the difficulty of shorting, are discussed in detail in the next section. Note that 24,542 (approximately 30%) of the observations correspond to negative rebate rate spreads.

III. Put-Call Parity: Empirical Tests

In this section, we perform an initial empirical analysis of equation (2). Ceteris paribus, without any underlying theory, we might expect 50% of the violations of equation (2) to be on either side. However, the limited arbitrage via short sales restrictions provides an asymmetry to equation (2). In particular, as stocks' market values rise above that implied by the options markets (if in fact that occurs), there is no arbitrage mechanism that forces convergence. On the other hand, if stock prices fall below their implied value, one can arbitrage by buying shares and taking the appropriate option positions. Thus, to the extent short sales constraints are binding, if prices deviate from fundamental value, equation (2) can be violated in one particular direction.

We provide three formal examinations related to equation (2). First, using the midpoints of the option quotes and the closing price of the stock, we evaluate violations of equation (2). In addition, we directly relate these violations to the spread between the rebate rate and the prevailing market rate. To preview the major results, there are violations of put-call parity primarily in the direction of the asymmetry induced by binding short sales constraints.

Second, in order to better understand this latter point, we investigate the relation between both the magnitude and direction of these violations and the rebate rate spread. As a test of robustness, we include a number of other possible explanatory variables such as ones related to liquidity in both the options and equity market, and underlying characteristics of the options. While some of these variables do have explanatory power, they tend to be small relative to the rebate rate spread. Most important, the rebate rate spread results are robust to the inclusion of all these variables.

Third, the analysis so far assumes transactions take place at prices at the midpoint of the quoted spread. As an alternative, we assume that all purchases and sales in the options market are done at the ask and bid prices, respectively. We also build into the analysis the assumption that the investor can short but at the cost of the rebate rate spread. This provides us with a more stringent test of the put-call parity condition. We still document important violations though they are significantly reduced in number. We view these violations as evidence that the rebate rate measures more than just the explicit cost of shorting. While these transaction costs-based results cannot explain why stock prices and their option-implied values drift apart, it does explain why investors do not go to the options market to duplicate share purchases. Alternatively, to the extent prices deviate from fundamental values, these deviations are bounded by the magnitude of the transactions costs and direct shorting costs.

A. Tests of Put-Call Parity

We investigate equation (2) by taking the midpoint prices of all the option pairs in our filtered sample, the corresponding stock, and the prevailing market interest rate (see the appendix for details about this interest rate). Table 2 reports both the percentage of violations of put-call parity in both directions, as well as estimates of the cross-sectional distribution of the traded stock price value divided by the option-implied stock price value. That is, in the latter case, we look at the ratio $R \equiv 100\ln\left(S/S^*\right)$, where

S^*=PV(K)+C-P+EEP. To the extent that there are asymmetric violations due to short sales constraints, we would expect R to exceed 0.

There are several interesting observations one can make from the results reported in Table 2. First, in the sample period studied here, R exceeds 0 for almost two-thirds of the sample. As mentioned previously, ceteris paribus we would expect this number to be 50%. In fact, it is possible to show that, under the null that the true probability is 50%, the 5% tail is approximately 50.70%; thus, the actual percentage of 65.10% is statistically significant at any measurable level.

In calculating the 5% tail above, it is critical to adjust for the dependence across the observations. Empirically, there is a negligible cross-sectional correlation between observations for different firms, even contemporaneously; therefore, we only control for serial dependence. It is impossible to estimate the autocorrelations separately for each firm because the data are sparse—on average each firm only has observations for 46 of the 118 dates (see Table 1B). Consequently, we impose the restriction that the autocorrelation function is the same for every stock. For the full sample, the stock price ratio R has a first order autocorrelation of 0.60, and autocorrelations decline slowly for longer lags. Not surprisingly, the binomial variable that measures whether R exceeds 0 has a much lower first order autocorrelation of 0.28. Nevertheless, the variance of the estimate of the percentage of positive ratios (i.e., the average of the binomial variable) is more than six times larger than under the assumption of independence. The 5% tail would be 50.28% based on an assumption of independence. The overall effect of the serial dependence is to make similar upward adjustments to the standard errors and downward adjustments to the test statistics that are reported in the tables and discussed later in the paper.[6] Finally, we also adjust for heteroscedasticity where appropriate, again assuming that the form of heteroscedasticity is the same across all firms.

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[6] An alternative way to adjust for the serial dependence in each stock's put-call parity violation is to restrict ourselves to one observation per firm. Specifically, we selected the observation for each firm with a rebate rate spread closest to the median value for that firm. The disadvantage of this approach is that it throws away data and we lose the time series structure of our analysis. The advantage is that it requires fewer assumptions on the underlying distribution of the data. (We thank the referee for this suggestion.) We re-ran the results of Tables 2, 3, 5 and 8 using this sample of 1734 observations. The results are similar in spirit to the ones documented in the text, and, if anything, are a little more dramatic. We conjecture that this latter effect might be due to a reduction in the noise in the data by eliminating extreme rebate rate spreads.

Second, consistent with this asymmetry, the median and mean of *R* are 0.30 and 0.20, respectively. While these estimates are significant at conventional levels, the magnitudes do not seem particularly large. Moreover, in studying the cross-sectional distribution of *R*, the 1% and 99% tails are –2.93 and 4.42 respectively. The tails of *R* are asymmetric but not markedly so, further suggesting that while the violations occur, they tend not to be large. Note that these observations look at the sample unconditionally. As discussed in Section II.A, deviations from fundamental value are not sufficient to generate violations of put-call parity. At a minimum, there must also be some form of limited arbitrage. Therefore, we break the sample into two distinct groups – one with rebate rate spreads equal to zero, and the other with negative rebate rate spreads. If negative spreads map one-to-one with short sales restrictions, then this partition represents one way to condition on stocks that are subject to limited arbitrage.

Table 2 reports the results using the rebate rate partitioning of the data. The first point to note is that of the 80,614 option pairs, 24,542, or approximately 30% of the observations, have negative rebate rate spreads. However, as described in Section II.C, there is reason to believe that rebate rate spreads are subject to some measurement error, suggesting that observations of small negative rebate rate spreads may not be that informative. It is difficult to determine whether small negative spreads are simply a result of nonsynchronous observations of the rebate rate across stocks or measure a true short selling cost. Thus, we also condition on more significant negative spreads of 1% or greater. This reduces the number of observations to 8,699, or still 10.8% of the sample. It seems that difficulty in shorting stocks is a common phenomenon in our sample.

Second, the option pairs with negative rebate rate spreads also have a greater percentage of put-call parity violations in the expected direction, that is, 69.50% versus 63.17%. These differences are significant at any measurable level with a standard normal test statistic equal to 7.19.[7] Interestingly, the occurrence of these violations and the underlying ratios are also more persistent for the negative rebate rate stocks. To the extent that rebate rate spreads are persistent, a conjecture that we verify later, this evidence is consistent with short sales constraints being meaningful. Third, the median and mean of the ratio *R* are significantly greater for these negative rebate rate stocks, i.e., 0.35 and 0.61 versus 0.16 and 0.16, respectively. Fourth, and most important, the tails of the distribution of *R* show that, while the 1% tails are similar for the two samples (i.e., -3.04 versus –2.87), the 99% tails are dramatically different (i.e., 7.68 versus 2.82). The theory suggests that the distribution of *R* should be asymmetric as the limited arbitrage appears through the difficulty in shorting stocks, i.e., when $S > S^*$. Extreme differences here are over 5.0% when the rebate rate is below its normal rate. Finally, these results are substantially more dramatic when we condition on spreads less than –1%, with the mean of *R* doubling to 1.21%, the 99% tail increasing to over 10%, and the proportion of positive violations exceeding 76%. These results are consistent with the measurement error hypothesis, but they also suggest a relation between the magnitude of the spread and violations of put-call parity. We explore this issue below.

B. The Rebate Rate and Put-Call Parity Violations

Table 3A reports regression results of *R* on the rebate rate spread using the full sample, as well as conditioning on just negative rebate rate spreads. There is a strong negative relation between the rebate rate spread and *R*. While this is expected given the previous results, Table 3A allows us to quantify both the magnitude and statistical significance of this relation. For example, conditional on a negative rebate rate spread, a one standard deviation decrease in the rebate rate (i.e., 2.77%) leads to a 0.67% increase in the relative mispricing between the stock price and its implied value from options. The corresponding t-statistic is over 8, which represents significance at any imaginable level.

In the context of the above regression, one way to address the issue of whether the rebate rate measures the actual cost of shorting versus the difficulty of shorting would be to regress *R* on the rebate rate spread for all the observations, but include a dummy variable for whether the rebate rate spread is zero. If the rebate rate proxies for the difficulty of shorting, then we would expect to see a discontinuity at zero. In other words, a very small but negative rebate spread should have different implications than a zero

[7] All the statistical tests of positive violation probabilities in the paper use the well-known DeMoivre-Laplace normal approximation to the binomial distribution albeit adjusted for serial dependence in the data as described previously. Given our sample sizes, this asymptotic approximation is essentially perfect.

rebate rate spread. As expected, the coefficient on the rebate rate is the same; however, the dummy variable is statistically significant, albeit small, i.e., -0.07%. Thus, there is only a small jump in the magnitude of the violation once the rebate rate goes negative.

The empirical fact that the rebate rate spread is strongly related to the magnitude of the put-call parity deviation is consistent with the theory of limited arbitrage. However, there are other potential explanations. For example, perhaps the put-call parity deviation reflects the underlying liquidity in the market, and the rebate rate spread simply proxies for this liquidity (or lack thereof). To test this hypothesis, Table 3B reports regressions of *R* on the rebate rate spread, proxies for liquidity in both the options and equity market (i.e., open interest, option spreads, option volume and equity volume), and underlying characteristics of the options (i.e., implied volatility, moneyness and maturity). Several observations are of interest.

First, the evidence for rebate rates is robust to the addition of liquidity controls in the regression. In fact, the coefficient on the rebate rate spread actually increases slightly from –0.24 to –0.26, and the statistical significance is also of similar magnitude. Second, if we drop the rebate rate spread from the regressions, then the R^2 drops from 18.1% to 4.0%, which suggests the rebate rate spread is by far the most important factor for explaining put-call parity deviations. Third, to the extent the liquidity variables have some explanatory power and are statistically significant, their coefficients for negative rebate rate stocks actually go in the opposite direction than one might theorize. That is, the greater the liquidity, the greater the put-call parity deviation. We take this as evidence of something real going on with these stocks. In other words, the "action" in the options and equity market is consistent with investors increasing their interest and trading in these markets as assets prices drift further from their fundamentals (subject to the difficulty of shorting). For zero rebate rate spread stocks the results are less conclusive, with the two significant coefficients working in opposite directions in the full specification. Finally, one statistically significant characteristic of stocks is their implied volatility. Higher volatility stocks tend to have lower put-call parity deviations. It is possible that this may be related to our measure of early exercise premia as low volatility tends to reduce the value of holding the option. However, this is theoretically important only for options in-the-money. Alternatively, volatility might proxy for some characteristic that helps explain put-call parity violations in the context of short sales restrictions.

In the regression analysis so far, we have ignored the length of the option and therefore the predicted magnitude of the rebate rate over its life. Given an estimate of the rebate rate costs per option, we can estimate the relation between the magnitude and direction of the put-call parity violation of an option and its particular shorting costs. To better understand the properties of these rebate rate costs, we need to develop a rebate rate model. The intuition from the model is that one might expect the "specialness" to subside or get worse over time depending on current market conditions. Alternatively, even if a stock is not "special" today, there may be some expectation that it will be in the future. In theory, this expectation of future limits on arbitrage could drive a wedge between the equity and options market.

Our model assumes that rebate rate spreads follow a three-state Markov model, where the states are defined as rebate rate spreads of zero, between zero and –0.5%, and less than –0.5%. The transition probabilities between these states are estimated from the data. Conditional on negative rebate rate spreads and remaining in the current state, we assume an autoregressive time series model (an AR(1)) for the rebate rate over the next period (again estimated from the data for each state). For transitions between states, we estimate the conditional expected rebate rate spread, conditional on the prior and current state. Thus, each period, we calculate the probability that the stock will go or remain special from week to week over the remaining life of the option, and then evaluate the cost that way. In particular, we estimate the average cost of shorting over the life of the option. The assumption we make here is that past rebate rate spreads are sufficient to describe the expected movements in these spreads. Table 4 reports the results from the estimation of the model.

Specifically, the probability transition matrix (Table 4B) shows that, conditional on not being special, the probability of going special from week to week is very small, that is, approximately 3.93%, only 0.59% of which is for rebate spreads below –0.5%. However, conditional on being special, the probability of remaining special is also high over the next week. For example, conditional on spreads between either 0 and –0.5% or less than –0.5%, the probability of going off special is 15.21% or 2.96% respectively, while the probability of remaining at the same degree of specialness is 77.79% or 88.58%. The mean reversion of the negative rebate rate spread is quite slow, i.e., the AR(1) coefficient equals 0.78 or 0.80 depending on the specialness degree (Table 4D). Thus, assuming the stock stays special and that its spread is highly negative, the rebate rate spread remains this way for quite a long time. This suggests that there are substantial costs to shorting certain stocks over the life of the option.

Table 3A reports regressions using Reb^A, the expected cost of short selling over the life of the option, derived from the aforementioned model (see Table 4) instead of using the current rebate rate. This allows us to incorporate the maturity of the option, which might in turn affect the violations of put-call parity. Both the explanatory power of the regressions (i.e., approximately 10%) and the economic implications of the coefficient estimates are very similar with and without the adjustment. For example, a one standard deviation decrease (i.e., 0.23%) in the adjusted rebate rate leads to a comparable 0.63% increase in the relative mispricing between the stock price and its implied value from options. One possible explanation for the similarity in the regression results is that the current rebate rate spread and our model-based short selling costs are highly correlated, i.e., 0.90.

Interestingly, when the regression is performed over all the observations, including current zero rebate rate spreads with the potential for going special over a given maturity, the explanatory power drops. This suggests that the rebate rate model is not particularly helpful in explaining mispricings for zero rebate rate stocks. Finally, if the rebate rate reflects only the extra income that a holder of the stock can make by lending it out (see Duffie, Garleanu and Pedersen (2001)), then the coefficient should be less than or equal to one in magnitude. In both Models 2 and 4 in Table 3A, the magnitudes of the coefficients are significantly larger than this bound, suggesting that something more is going on.

One natural question to ask is whether these put-call parity violations are consistent with the magnitude of short sale costs and other transactions costs in the options markets. This is an important question as there is some debate about the competitive nature of the equity lending market. In the next subsection, we bring evidence to bear on this question.

C. Transactions Costs and Put-Call Parity Violations

Over a given horizon, investors can choose to purchase shares directly or replicate their payoffs by going to the options market. Why would any investor choose the former if the latter market provides a much cheaper way of achieving the same payoffs? One possibility might be that the options market is too expensive to transact in, i.e., its lack of liquidity translates into high transactions costs (e.g., Nisbet (1992)). To investigate this hypothesis, we compare separately a long and short position in the stock versus the replication in the options market. In performing these calculations, we assume that the stock purchase is done at the last transaction price (be it a buy or a sell) and that one can borrow or lend at the same rate. In contrast, we assume purchases and sales of options are at the ask and bid prices, respectively. For example, we compare the prices of being long the stock to buying the call at its ask, selling the put at its bid, and lending the $K strike price. That is,

$$S^L \approx PV(K) + C^A - P^B + EEP\,, \tag{3}$$

where C^A and P^B are the ask and bid prices of the call and put, and S^L represents a long position in the stock. Similarly, a short position in the stock can be written as

$$S^S \approx PV(K) + C^B - P^A + EEP\,, \tag{4}$$

where S^S represents a short position in the stock. Combining (3) and (4) together provides a bound on how much the stock price can drift:

$$S^S \le S \le S^L\,. \tag{5}$$

The results are reported in Table 5A. As is clear from Table 2, there are many fewer cases in which the stock price is below its implied value, especially if we also condition on stocks facing limited arbitrage opportunities (i.e., negative rebate rate spreads). Thus, there are only a few cases in which the stock price drops below S^S. For example, Table 5A shows that only 2.73% of the observations have stock prices that violate this condition. In contrast, violations on the other side are more numerous, with 12.23% of the observations exceeding S^L. This means that, even in the presence of transactions costs (i.e., the bid-ask spread), it is cheaper to replicate payoffs using options than to purchase the shares directly. Why investors did not do this is a puzzle.[8]

These results are even more dramatic when we partition the sample of observations into groups with and without negative rebate rate spreads. Assuming that negative rebate rate spreads proxy for short sales restrictions, Table 5A shows that the violations are much more numerous for stocks that are short sale constrained. For example, the percentage number of put-call parity violations in the two samples is 19.51% versus 9.04% in trying to replicate a long position in the stock, with a corresponding mean violation of 2.71% in the former case. This difference suggests that the equity market prices are drifting further from fundamentals because, without short sales, the prices cannot be either driven back down through equity market sellers or arbitraged away in the options market. The fact that they drift will be addressed in Section IV below. On the other side of equation (5), and consistent with the asymmetric nature of short sale constraints, the violations are virtually identical, i.e., 2.65% versus 2.77%, for the two samples.

Given the persistence of short sales constraints as documented in Table 4, one might also expect the persistence of violations in the two tails to differ. In particular, stock prices less than the value of the synthetic short position may be partly due to measurement error, such as nonsynchronous trading in the stock and options markets, and thus should not persist from week to week. In fact, the autocorrelation of these violations is 0.23, less than half the autocorrelation of 0.58 for violations in the other tail of the distribution. Viewed slightly differently, the probabilities of seeing a violation for a particular stock in the following week, conditional on a violation this week, are 25% and 66% for the left and right tail, respectively.

Option spreads, however, are not the only transaction cost faced by investors. If an investor is able to short, then we know that the rebate rate spread represents the actual cost of shorting. There is some debate, however, whether investors can actually locate and, equally important, maintain the short position when the stock is special, i.e., when its rebate rate spread is negative. The evidence in Section III.B above suggests this

[8] At first glance, one reasonable possibility is that long-term investors may not wish to roll over their options positions from period to period (due to transactions costs). However, this argument does not hold

possibility may be empirically relevant. Nevertheless, it seems worthwhile taking the view that the equity lending market is a competitive market, and that the rebate rate represents the market rate all investors can obtain. In other words, there is limited arbitrage only to the extent that the rebate rate spread is negative, i.e., short selling and, therefore, arbitrage is attainable but at a cost.

Including the cost of shorting stocks when they are special implies a revision of equation (2), and therefore an adjustment to equation (5) above, namely

$$S^A \equiv S(1-\nu) = PV(K) + C - P + EEP\,, \tag{6}$$

where ν measures the spread between the rebate rate and the market rate. In theory, ν represents the cost of shorting the stock over the maturity of the option, which may or may not equal the current rebate rate spread. For our purposes, we employ the 3-state autoregressive model for rebate rates described in Section II.B above and documented in Table 4.

Table 5B looks at put-call parity violations assuming the rebate rate spread is a cost, as well as assuming that transactions take place at the bid and ask prices in the options market. Violations on the short sell side for negative rebate rate spread stocks are still more numerous, with 13.63% of the observations exceeding S^L versus only 7.82% for zero rebate rate stocks. While the drop from 19.51% to 13.63% once rebate rates are incorporated is clearly significant, it also shows that, even with all transactions costs taken into account, violations of put-call parity remain. Moreover, the mean of these violations is 2.84%. We feel this provides further evidence that the rebate rate spread represents more than just a cost of transacting, but also the difficulty of shorting in practice. As intuition, take the extreme case in which it is almost impossible to locate a short, i.e., infinite search costs. The rebate rates are obviously not minus infinity in these cases.

As a final look at the interaction between put-call parity deviations and transactions costs, we conduct the following volatility decomposition experiment. We take our measure for put-call parity deviations, *R*, without the adjustment for the early exercise premium, rebate rate spreads and transactions costs in the options market. Conditional on negative spreads, how much of the variation in *R* is due to these various

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for U.S. equity options as the investor can choose to take delivery of the stock upon exercise.

factors? Individually, the rebate rate, early exercise premium and the call and put spreads explain 10.8%, 1.1% and 1.2%, respectively.[9] Collectively, they explain 14.1%. Dropping the rebate rate, exercise premium and spreads from the regression reduces the 14.1% to 3.4%, 13.2% and 12.3%, respectively.

These results imply that shorting costs play a much more important role than the other factors. This result is economically intuitive. Negative rebate rate spreads are consistent with the stock being difficult to short. Shorting arises endogenously, possibly through diverging opinions in the stock market.[10] If this is the case and there is market segmentation between equities and options (for whatever reason), then put-call parity deviations are implied (e.g., Ofek and Richardson (2002)). The other factors make no such prediction. In fact, it is a misnomer to think that just because a particular option faces higher transactions costs that necessarily put-call parity deviations should be higher for that option. The theory still implies the assets should be priced relative to their underlying payoffs. In fact, empirically in our sample, the put-call parity deviations are actually lower in the presence of higher transactions costs.

IV. Explaining the Put-Call Parity Violations: Empirical Analysis

Several important implications can be drawn from the stylized facts of Section III. First, there is substantial evidence that across the universe of stocks there are limits to arbitrage. A significant percentage of these stocks face short sales restrictions, which have an effect on the ability to conduct arbitrage between the equity and options markets. Second, and related, these limits to arbitrage do lead to violations of put-call parity such that stock prices and their corresponding implied values from options markets deviate from each other. Third, transactions costs, whether the actual cost of shorting or the bid-ask spread in the options market, seem to limit the magnitude of these deviations in many cases. Moreover, even with transactions costs, the question of why the stock and options markets deviate in the first place remains.

[9] For brevity, the regressions that yield these results are not reported in a new table.
[10] Of course, shorting might result from hedging needs and may have nothing to do with differing beliefs about the stock's future payoffs.

There are a few theories in the finance literature that might help answer this question. For example, Duffie, Garleanu and Pedersen (2001) argue that stock prices can deviate from "fundamental value" because the stock price should also include the benefits derived from being able to lend out the stock to short-sellers. Of course, not all stocks can be shorted, so that the magnitude of this effect might be small. This point aside, put-call parity could be violated because the added benefit from the cash flow stream of possible share loans is similar to a stream of dividend payments. Dividends, if not accounted for, will lead to violations of equation (2). We have also ignored frictions such as taxes and differences between borrowing and lending rates, although it is not clear exactly how these factors will affect put-call parity violations, especially in relation to the presence of short sale constraints. Finally, fluctuations in the value of the control rights associated with the equity, but not with the synthetic position in the options market, might also generate put-call parity violations under specific circumstances. This control rights effect also acts like a dividend if the value declines prior to option expiration. Moreover, there is anecdotal evidence that stocks go special during corporate events that are associated with changes in control, such as takeovers. Nevertheless, it is difficult to believe that declines in the value of control rights are pervasive enough to explain the observed results.

Alternatively, the growing literature in behavioral finance also suggests a possible explanation. A number of papers (e.g., Miller (1977), Chen, Hong and Stein (2001), and Ofek and Richardson (2002), among others) show that, with investors having diverse beliefs and facing short sales constraints, prices can drift from fundamental values. Suppose there exist periods in which there are both overly optimistic investors and rational investors. The overly optimistic investors bid the prices of stocks up, but, due to short sales constraints, the rational investors do not simultaneously bid the shares back down. Thus, the stock price tends to drift above the value associated with aggregate beliefs because there is no mechanism to push prices back to the true aggregate value.

Of course, the fact that stock prices drift from fundamental value does not necessarily lead to put-call parity violations. Why would these overly optimistic investors buy shares in the equity market when they could achieve the same payoffs at lower costs using options? One must also be willing to argue that the equity and options markets are sometimes segmented in terms of their investor classes; that is, these overly optimistic investors choose not to invest in the options market. One potential justification for this segmentation is that investors in the equity market trade frequently enough and in high enough volume that transaction costs and lack of depth in the options market prevent them from duplicating these trading patterns. Cochrane (2002) provides empirical evidence that these characteristics were present in numerous stocks during our sample period. Rational investors enter the options market, but, with short sales restrictions, cannot arbitrage between the two markets. The remainder of the paper focuses for the most part on building implications from this behavioral theory and then bringing evidence to bear on its validity.

Note that, even in the above world with segmented markets, there still may not be put-call parity violations. Because option payoffs are based on the underlying share price, both the likelihood and magnitude of the put-call parity violation depends on the probability and degree to which stock prices will eventually revert to fundamental value. Consider the extreme case in which prices never revert to their fundamental value. In this case, put-call parity will not be violated, as options are derivatives of the stock and will reflect the stock price's actual stochastic process.[11] This point is actually a powerful way to generate implications of the behavioral theory. Below, we describe three such implications and corresponding tests.

A. The Maturity Effect of Put-Call Parity Violations

Under the behavioral theory outlined above, and with short sales restrictions, put-call parity violations can occur if options investors have some belief that the stock price will revert to fundamental value. Consider rational investors who know everything about the fundamental stock price process, as well as the actual stock price process being driven by some degree of irrationality. The prices they pay in the options market (i.e., long puts, short calls) will reflect both the probability that stock prices will revert to fundamental value and the expected magnitude of this reversion over the life of the option. Thus,

[11] Of course, this is only true for non-dividend paying stocks. Since we restrict our sample to such stocks, the intuition is especially relevant.

ceteris paribus, the maturity of the option should be very much related to the nature of the put-call parity violation. Note that there are other explanations. For example, the income story of Duffie, Garleanu and Pedersen (2001) will also produce a similar maturity effect. Alternatively, the difficulty of shorting may increase with the horizon length, as investors' shorts are more likely to be recalled.

Table 6 reports several stylized facts related to put-call parity violations and the maturity of the options. Specifically, whereas previous tables focused on intermediate-term options with a median expiration of 131 days, we now look at options with three different ranges of maturities: (i) short- (i.e., 30 to 90 days), (ii) intermediate- (i.e., 91 to 182 days), and (iii) long- (i.e., 183-365 days) maturity options (see the data description in Section II.C). Given our other filters, this increases the overall number of option pairs from 80,614 to 189,037 over our sample period.

As can be seen from Table 6, the violations (both in number and magnitude) generally increase for longer maturity options. Specifically, the mean violation for long maturities is 0.38% versus 0.30% and 0.21% for medium and short maturity options, respectively. These differences get even stronger when we condition on negative rebate rate spreads. For example, the mean violations increase to 0.86%, 0.61% and 0.37%, respectively. Perhaps, most important, the magnitude of the tails of the distribution of violations is much larger for long maturity options only on the asymmetric side associated with shorting. This is consistent with the theory of limited arbitrage mattering but only to the extent that there is the possibility that prices will revert to fundamental values (as measured by the maturity of the option). Since the maturity effect describes more the magnitude of the violation, the percentage of violations is similar across maturities. These facts taken together suggest a strong relation between put-call parity violations and the option's maturity.

In order to better capture the magnitudes of these differences as the rebate rate spread gets more negative (i.e., the limits on arbitrage become greater), Figure 1 provides a graphical representation of the regression of R on the rebate rate spread for the three partitions of the data – short, medium and long maturity options. As shown in the figure, significant put-call parity violations occur under two conditions: (i) negative rebate rate spreads (i.e., limited arbitrage), and (ii) long versus short maturity options (i.e., a higher probability of reversion). These results are consistent with the theory of behavioral biases amongst some investors in the equity market.

B. Structural Shifts in Mispricing

Section IV.A described and showed empirically why the put-call parity violation is related to the maturity of the option (at least in terms of the behavioral theory). However, the put-call parity violation is also related to the size of the disparity between the stock price and its fundamental value. That is, suppose all the conditions are met to satisfy the behavioral explanation. If the put-call parity violation is small, it could be because the maturity of the option is short (i.e., a low probability of reversion) or that the mispricing is small (i.e., the stock price reflects fundamental value).

To get at this latter point, it is worthwhile conditioning on periods of possible equity mispricing and then looking for violations of put-call parity in the options market. Of course, the difficulty with implementing such a test is that we do not know ex ante when these periods occur, if ever. Nevertheless, Table 7 reports three types of tests. First, as one possibility, we choose the so-called crash of the NASDAQ as the date of the structural shift in mispricing (i.e., the first two weeks of April 2000). We first calculate both the percentage and magnitude of put-call parity violations pre- and post-crash as defined by the pre-March 2000 and post-April 2000 periods, respectively. These results are reported in Table 7A. Specifically, conditional on negative rebate rate spreads, the mean and median levels of R are 0.69% versus 0.56% and 0.49% versus 0.28%, respectively, for pre- and post-crash. These differences are statistically significant at the 10% level. These results are suggestive of put-call parity violations being affected by the NASDAQ crash. If the reader believes the crash was partly due to a correction in market mispricings, then these results are consistent with the aforementioned story of segmented markets, limited arbitrage and put-call parity violations.

Second, using the pre- and post-crash periods, we test formally for the relation between put-call parity violations and the rebate rate spread. Table 7B provides regressions pre- and post-crash between the violations R and rebate rate spreads, as well a formal test of the difference. Several points are important here. First, the constant in the regression is higher pre-crash than post-crash, reflecting the above result that larger violations of put-call parity are present in the earlier subsample. Second, the slope coefficient is larger in magnitude pre-crash, which suggests that these violations are more sensitive to the limited arbitrage restrictions. Of course, these restrictions are only relevant if mispricings do exist. The test for a structural change is statistically significant at the 10% level.

Finally, in order to avoid specifying a particular date for the structural shift, we look at the relation between put-call parity violations and a continuous measure of mispricing, namely the P/E ratio of the S&P500. While the P/E ratio reflects the present value of growth opportunities and therefore can vary for quite rational reasons, we treat high (low) P/E ratios as reflective of overpricing (underpricing) for our purposes. Figure 2 graphs the median put-call parity violation magnitude for stocks with and without negative rebate rate spreads and the S&P500 P/E ratio on a quarterly basis.

Several observations are in order. First, and perhaps most interesting, the time series pattern in violations appears to match closely that of the P/E ratio of the S&P500, our measure of overvaluation. When the P/E ratio is high, at the beginning of the sample period, put-call parity violations are relatively large in magnitude. As the P/E ratio falls, the magnitude of violations also drops. The figure presents the data on a quarterly basis in order to smooth out some of the noise for presentation purposes, but, on a monthly basis, the correlation between the P/E ratio and the median violation for negative rebate rate spread stocks is an astonishing 0.76. This somewhat casual evidence clearly suggests a strong and positive relation between valuation levels in the market and the magnitude of put-call parity violations. Second, consistent with Table 7, there appears to be a structural shift in the magnitude of these violations in mid 2000. Anecdotally, this time frame is associated with the so-called bursting of the tech bubble, which many researchers consider a period of mass overvaluation. Of course, the P/E ratio also falls dramatically during this period. Third, before mid 2000, and after early 2001, the magnitudes of violations are fairly stable. The magnitudes, however, are at completely different levels. Again, this is consistent with the earlier period being governed by greater mispricings, and it also parallels the behavior of the P/E ratio. Fourth, the difference in magnitudes between the groups conditioned on rebate rate spreads is interesting. There is always a substantial difference, which is consistent with the rebate rate spread proxying for limited arbitrage conditions. Interestingly, after early 2001, there are few violations for normal rebate rate stocks, which is consistent with the forces of arbitrage. However, during the so-called bubble period, substantial violations still take place for stocks with normal rebate rates (albeit less than for stocks with negative spreads). Recall that the stocks in our sample do not pay dividends, which generally puts many of our stocks in the technology sector (e.g., technology, electronic equipment, semiconductor and internet firms account for about 40% of the sample). Even if the rebate rate is normal, and this suggests (though not definitively) that one can short the stock today, there might be an expectation that shorting will be difficult in the future. Thus, violations can still occur over the life of the option.

C. Forecasting Returns

Consider the behavioral model outlined above. In that world, option prices deviate from equity prices because rational investors price the assets in the options markets, and irrational investors price assets in the equity market. Arbitrage is not possible because investors cannot short in the equity market. Two factors limit the magnitude of the divergence between these markets: (i) some shorting (albeit at a cost) can take place, and (ii) there must be an expected convergence of these markets during the life of the option. With respect to this latter factor, this convergence suggests some form of predictability in stock returns. That is, assuming the rational investors accurately reflect the “truth” on average, we would expect stock returns to fall over the life of the option conditional on a put-call parity violation and/or a negative rebate rate spread. Our analysis is similar in spirit to that of Jones and Lamont (2001), who also look at the ability of short-selling costs to predict future returns. The key differences are that they examine a smaller cross-section of stocks (90 on average) for the period 1926-1933, and they condition only on short-selling costs and not on information from the options market. Nevertheless, their conclusions are similar.

Table 8A reports the average excess stock return over the life of the option, conditional on available information such as the current put-call parity violation, rebate rate spread, and combinations of these variables.[12] The results show strong evidence that these mean excess returns are negative. For example, conditional on a negative rebate rate spread, the mean excess return over the life of the option is –7.08% versus 0.70% for zero rebate rate stocks. The result is magnified if we condition on even greater rebate rate spreads, such as –0.5% in which case the mean return drops to –9.96%. All of these results are strongly statistically significant. While of smaller magnitude, conditioning on put-call parity violations also provides similar results. For example, for violations greater than 0.0% and 1.0% respectively, the mean excess returns are –2.54% and –4.49% over the life of the option. Finally, to the extent that the rebate rate and the violation may contain some differential information about future stock price movements, the table also reports mean excess returns for combined partitions of the data. Generally, the excess returns are even more negative. For example, by conditioning on negative rebate rate spreads less than –0.5%, and combining that with put-call parity violations greater than 0.0% and 1.0%, we find that excess returns fall from –9.96% to –11.21% and –12.57%, respectively.

These results, and to a lesser extent the regression results that follow, should be interpreted with some caution for two reasons. First, the returns are calculated over the life of the option; therefore, we are averaging returns across horizons ranging from 91 to 182 days. Second, we select stocks on every date; thus, the same stock may be selected on consecutive dates. The expiration date of the option may or may not be the same for these two observations, but in either case we include both returns in the sample. Clearly these returns will have a substantial overlap. We adjust for this overlap when calculating the reported test statistics using an empirical estimate of the correlation between return observations on a single stock, but this adjustment is imperfect. An alternative approach is to eliminate the serial correlation completely by choosing only one observation per stock (see footnote 6). This analysis generates qualitatively similar results.

To examine these relations more closely, Table 8B also reports more general tests of stock return predictability using both the rebate rate and the put-call parity violation R as predictive variables. In particular, for each option pair, we take the excess return on the

[12] The theory implies that the difference between the option-implied stock price and the market price reflects the excess risk-adjusted return. We measure this excess return on each stock by subtracting out the

stock over the life of the option and regress it on these variables. Consider first the magnitude of the put-call parity violation. In theory, this difference represents the expected drop in risk-adjusted returns over the life of the option. Thus, to the extent that our measure of excess returns captures this risk-adjusted return, we would expect a coefficient of –1, i.e., a one-for-one drop in returns per unit of overvaluation in the equity market. The estimate from the data is very close, i.e., –1.28, and is statistically indistinguishable from –1 (with a standard error of 0.29).

With respect to the rebate rate spread, we run a regression of future excess returns on the rebate rate spread and on a dummy variable taking on the value of 1 if the rebate rate spread is zero. The results also suggest predictability of returns. However, the magnitudes are considerably greater with respect to the rebate rate spread. For example, a negative rebate rate spread alone suggests a 6.15% drop in future expected returns over the life of the option. This is strongly significant with t-statistics in excess of 4.5. The economic interpretation is that the mere difficulty in shorting corresponds to a 6.15% fall in future prices. In terms of the magnitude of the rebate rate, there is an almost one-for-one drop in stock returns per unit of the rebate rate spread. This result means that a one standard deviation drop in the rebate rate spread results in a drop of 1.73% in future expected returns on the stock over the life of the option. Note, however, that the rebate rate spread is an annualized number and does not take into account the maturity of the option or the possibility that rebate rates will change in the future. When we use the expected cost over the life of the option (Reb^A) as the independent variable, the coefficients are more than an order of magnitude larger. The decline in the stock price over the life of the option is much greater than can be explained by the magnitude of shorting costs, assuming, of course, that our time series model for rebate rates is reasonable. Interpreting the adjusted rebate rate spread as the income (dividend) that can be generated by lending out the stock implies a negative coefficient, consistent with the results, but the magnitude should be less than 1 (Duffie, Garleanu and Pedersen (2001)). These results are consistent with those of Jones and Lamont (2001), who also find in their sample that returns exceed the associated borrowing costs on the stock.

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corresponding industry return over the life of the option.

Another way to evaluate the forecastability of returns using these measures of limited arbitrage and short sales restrictions is to evaluate a trading strategy that takes all the relevant costs into account. In particular, let us assume that shorting can take place albeit at the rebate rate spread. We form five different zero-investment portfolios and follow their performance from week to week. In particular, we form a long portfolio of the relevant industry returns and a short portfolio of stocks satisfying one of five different criteria: (i) stocks with a negative rebate rate spread less than –0.5%, (ii) stocks with a negative rebate rate spread less than –1.0%, (iii) stocks with put-call parity violations, (iv) stocks with put-call parity violations greater than 1%, and (v) stocks with both (i) and (iii). The portfolio has equal weights on all stocks satisfying the relevant criteria, and stocks are held until the expiration of the corresponding option.[13] Each week, the return on the portfolio is adjusted for the costs of shorting as described by the *actual* rebate rate spreads on the stocks in the portfolio.

Figure 3 graphs the returns on portfolios 1, 3 and 5 over the sample period. Irrespective of the criteria, the portfolios of stocks (with short signals) perform miserably relative to the weighted portfolio of corresponding industry returns. Thus, the zero investment portfolio produces large excess returns. For example, the cumulative returns on portfolios 1, 3 and 5 are approximately 38%, 20% and 66%, respectively. As can be seen from the figure, the performance of the portfolio over the sample period suggests pervasive, and fairly consistent, poor returns on stocks that are subject to arbitrage constraints. We take this as evidence that there exist binding arbitrage constraints for a reason. Even if the above strategy is not implementable (i.e., the rebate rate represents more than just the cost of shorting), it presents a considerable puzzle to financial economists. Specifically, who is buying these arbitrage-constrained stocks at these inflated prices?

Table 9A documents the statistical properties of all five portfolios. While all the portfolios produce positive mean excess returns, the returns are higher the greater the

[13] While our non-dividend paying stock sample includes a variety of technology, pharmaceutical, electronic equipment, semiconductor and internet firms (approximately 10% of each), among 30 other industries, the portfolio companies (e.g., consider portfolio 5) are more concentrated in internet firms (25%) and pharmaceutical firms (20%). Of course, if one's view is that these were both overpriced industries and subject to arbitrage limits, there is nothing surprising about this. It is important to note, however, that the

arbitrage constraint. Changing the rebate rate criteria from –0.5% to –1.0% changes daily mean excess returns from 0.066% to 0.092%. If we adjust these returns for the daily cost of shorting (as defined by the actual rebate rate spread), the corresponding net mean returns are 0.057% to 0.081%, representing only a slight drop. Interestingly, the volatilities across the portfolios are very similar. Thus, the standard risk-return tradeoff is not the source of these differences. While the means increase, the volatilities are stable at 1.00% and 1.01%, respectively.

The results above are adjusted for industry effects, but it is now fairly standard in the literature to also adjust returns for the three Fama and French (1992) factors, i.e., the market return, the return on a high minus low book-to-market portfolios, and the return on small versus large firm portfolio returns. Estimating the coefficients on these factors using our five portfolio returns, we can estimate αs for each portfolio. Table 9B shows that, on the whole, the αs tend to drop uniformly across our various portfolios relative to the industry adjustment alone, but only slightly. Moreover, because the variance of the residual has been reduced, the statistical significance actually increases for some of the portfolios. For example, for R>1%, though the gross mean αs drop from 0.94% to 0.77% when we include the Fama-French factors, the significance is below the 1% level versus the 5% level before. The general conclusion can be drawn that the substantial gross and net returns documented in Table 9B are not driven by movements in aggregate factors over this period.

V. Conclusion

Shleifer (2000) argues that there are two necessary conditions for behavioral finance to have some chance of explaining financial asset prices, that is, for prices to deviate from fundamental value. The first is that some investors must be irrational, namely they must ignore fundamental information or process irrelevant information in forming trading decisions. The second is that there must be some limits to arbitrage such that this irrationality cannot get priced out of the market. In this paper, we look at a unique

returns are adjusted for their corresponding industry return, and the remaining 55% of firms come from other sectors.

experiment that gets at these conditions. Specifically, by investigating the relation between equities and their corresponding options both under conditions of severe arbitrage constraints and little or no constraints, we are able to investigate this issue directly. The power of the analysis is greatly increased by looking across a large sample of stocks over a three-year period.

We document several stylized facts that pose considerable problems for rational asset pricing models. First, there are significant periods and numbers of firms subject to short sales constraints. For example, we find that stocks have negative rebate rate spreads, i.e., some degree of specialness, over 31% of the time in our sample. Second, the more binding the constraint, the greater the put-call parity violation. Specifically, we show a strong relation between the rebate rate spread and the magnitude of the violation. This suggests a degree of mispricing across markets, although it is perhaps not arbitrageable. Third, these results are consistent with a behavioral explanation to the extent that both the number and magnitude of these violations seem related to periods of mispricing and expectations about these mispricings being eventually reversed.

One might conclude that the results in this paper support the foundations of behavioral finance, namely that there are enough irrational investors to matter for pricing assets. Researchers should find it heartening, however, that the forces of arbitrage do appear to limit the relative mispricing of assets. That is, there is a clear relation between arbitrage constraints (e.g., transactions costs, rebate rates and specialness in general) and the level of mispricing. On a more negative note though, it remains a puzzle why any investor would ever wish to purchase such poorly performing stocks. We hypothesize that any explanation based on completion of markets will be a difficult story to swallow.

Appendix

All options data come from the Ivy DB database provided by OptionMetrics. This database contains option prices and related data "for the entire US listed index and equity options markets" (IVY DB File and Data Reference Manual). The pricing data are compiled from raw end-of-day pricing information provided by Interactive Data Corporation. Other than contract specific information (e.g., strike price, expiration date), our analysis uses two primary pieces of data:

1. Daily option (put and call) quotes (bid and ask prices), i.e., the best, or highest, closing bid price and the best, or lowest, closing ask price across all exchanges on which the option trades.
2. Daily continuously compounded zero-coupon interest rates whose maturities match the expiration dates on the options. These rates are calculated using interpolation from a zero curve generated using LIBOR rates and settlement prices of CME Eurodollar futures. (See the IVY DB File and Data Reference Manual for details).

Some of our analysis uses the option prices at the midpoint of the spread, i.e., the average of the bid and ask prices. We also calculate the option spread, i.e, the difference between the ask and bid prices, as a percentage of the midpoint, as a measure of liquidity.

The rebate rate data come from a large dealer-broker and cover essentially all the stocks in the options database. Quotes for a given stock are sometimes missing, but we can detect no systematic pattern to these missing observations, and the number of missing observations is small. For each day and stock, we calculate the rebate rate spread (short selling cost) as the deviation of the rebate rate on that stock from the median rebate rate for that day, i.e., the "cold" rate. On every day, the majority of stocks have a rebate rate equal to the "cold" rate. Over time, the "cold" rate moves with prevailing market interest rates.

Starting with the above datasets, we select 118 dates between July 1999 and November 2001 that are approximately 5 business days apart. We then apply the following filters:

- We eliminate all dividend-paying stocks. Thus, American call options can be treated as European call options and no dividend adjustments are necessary in computing option values and implied volatilities.
- On each date, we eliminate options that have zero open interest. We use open interest as a proxy for liquidity in the options market. (Many of these options would also be eliminated by the moneyness filter discussed below since deep in- or out-of-the-money options tend to be the least liquid.)
- On each date, we eliminate stocks (and the corresponding options) for which we do not have rebate rate data. While the rebate rate database is comprehensive, there are sometimes missing quotes.
- On each date, we eliminate call and put options that do not have a corresponding put or call option with the same maturity and exercise price.

These filters leave us with pairs of matched call and put options on stocks with rebate rate data. Table 1A provides descriptive statistics on the options in this sample.

In order to maximize the quality of the data, we then apply a second set of filters:

- On each date, we eliminate stocks (and the corresponding options) with prices less than \$5.
- We eliminate option pairs with maturities less than 30 days or greater than 365 days.
- We eliminate option pairs that are either deep in- or out-of-the-money ($|\ln(S/K)|>0.3$).
- We eliminate option pairs if either the put or the call has a bid-ask spread that is greater than 50% of the option price (at the midpoint). This filter catches both recording errors and options with very low liquidity.
- We eliminate stocks (and the corresponding options) if the stock price ratio *R* exceeds 40.5 in absolute value. This filter also catches recording errors.
- We eliminate option pairs if it is impossible to calculate the implied volatility of the call option because the option price (at the bid-ask midpoint) exceeds the stock price less the present value of the exercise price.

Finally we sort the option pairs into 5 moneyness/expiration groups as follows:

1. At-the-money, short maturity ($-0.1<\ln(S/K)<0.1$, 30-90 days)
2. At-the-money, intermediate maturity ($-0.1<\ln(S/K)<0.1$, 91-182 days)
3. At-the-money, long maturity ($-0.1<\ln(S/K)<0.1$, 183-365 days)
4. In-the-money, intermediate maturity ($0.1<\ln(S/K)<0.3$, 91-182 days)
5. Out-of--the-money, intermediate maturity ($-0.3<\ln(S/K)<-0.1$, 91-182 days)

On any given date and for any given stock there may be multiple pairs that satisfy the moneyness and expiration criteria. If this is the case, we select the option pair that is closest to the middle of the range. Thus, there is only a single option pair per stock per date in the final sample. The reduction in the sample size from the full sample of over 1 million pairs to, for example, 80,614 pairs for the at-the-money, intermediate maturity sample is primarily due to the elimination of multiple option pairs for a stock on a given date and the moneyness/expiration grouping. The other filters eliminate relatively few observations.

The majority of the analysis is conducted with the at-the-money, intermediate maturity sample. The maturity effect (Table 6) is studied using the other two at-the-money samples. The effect of moneyness is studied using the other two intermediate maturity samples. Since moneyness has no apparent effect on the results, these results are neither reported nor discussed in the paper.

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Table 1: Sample Description

Panel A reports descriptive statistics for the full sample of paired options. The data span 118 dates between July 1999 and November 2001. The total number of option pairs is 1,359,461. Panel B reports descriptive statistics for the subsample of paired options with ln(S/X) of less than 10% in absolute value, and maturity between 91 and 182 days. If multiple options pairs fit the criteria for a single firm on a given date, then only one pair is selected. The total number of pairs in Panel B is 80,614, of which 24,542 have negative rebate rate spreads (Reb<0).

Panel A: Full sample of paired options

Variable	Mean	Median	5 pct	95 pct
Days to expiration	161.918	115.000	37.000	569.000
Ln(S/K)(%)	-2.361	-1.859	-55.513	50.456
Open interest - call	711.4	133	5	2655
Open interest - put	480.6	63	3	1661
Daily volume -call	31.9	0	0	103
Daily volume -put	15.5	0	0	40
Number of firms per date	1083.7	1104	963	1160
Number of option expirations per firm	2.5	2	1	5
Number of strikes per expiration	4.3	3	1	12

Panel B: At-the-money, intermediate maturity sample of paired options

Variable	Mean	Median	5 pct	95 pct
Stock price	32.195	23.813	7.520	83.375
Expiration(days)	134.554	135.000	95.000	177.000
Ln(S/K)(%)	0.047	0.000	-7.796	7.855
Open interest - call	416.510	101	5	1525
Open interest - put	289.110	50	3	1056
Daily volume - call	20.163	0	0	70
Daily volume - put	12.129	0	0	30
Spread - call(% of mid)	8.580	7.407	2.128	18.182
Spread - put(% of mid)	9.176	8.000	2.247	20.000
EEP(% of put mid)	0.829	0.709	0.181	1.815
EEP(% of stock price)	0.132	0.117	0.026	0.282
Implied volatility call(%)	74.751	72.813	39.219	118.125
Rebate rate spread(Reb<0)	-1.573	-0.460	-6.190	-0.020
Number of firms per date	683.169	693	561	781
Number of obs per firm	46.490	38	3	113
Number of options per firm	17.385	13	1	49

Table 2: Distribution of Unadjusted Stock Price Ratios

The table reports the distribution of the ratio $R \equiv 100\ln(S\ /S^{*})$ for at-the-money, intermediate maturity options, where S is the stock price and S^{*} is the stock price derived from the options market using put-call parity and assuming trades of options at the midpoint of the spread. The four test statistics and corresponding P-values test: (1) the equality of the mean ratios across zero (Reb=0) and negative rebate spread (Reb<0) stocks, (2) & (3) whether the probability of observing $R > 0$ equals 50% for the zero and negative rebate spread stocks, and (4) whether the probability of observing $R > 0$ is equal across zero and negative rebate spread stocks. The test statistics have an asymptotic N(0,1) distribution under the null hypotheses.

	All	Reb=0	Reb<0	Reb<-1
Obs	80614	56072	24542	8699
Mean	0.30	0.16	0.61	1.21
Percentiles				
1	-2.93	-2.87	-3.04	-3.41
5	-1.22	-1.19	-1.27	-1.37
10	-0.68	-0.67	-0.69	-0.68
25	-0.16	-0.18	-0.12	0.04
50	0.20	0.16	0.35	0.80
75	0.65	0.53	1.02	1.82
90	1.33	1.04	2.04	3.34
95	1.97	1.49	2.97	5.14
99	4.42	2.82	7.68	10.16
R<0(%)	34.90	36.83	30.50	23.80
R>0(%)	65.10	63.17	69.50	76.20

Test	**Stat**	**P- value**
E[R|Reb=0]=E[R|Reb<0]	9.08	0.00
Pr(R>0|Reb=0)=50%	28.92	0.00
Pr(R>0|Reb<0)=50%	25.92	0.00
Pr(R>0|Reb=0)=Pr(R>0|Reb<0)	7.19	0.00

Table 3: Regressions for Unadjusted Stock Price Ratios

Panel A reports linear regressions of the stock price ratio on rebate rate spreads. The dependent variable is the ratio $R \equiv 100\ln(S/S^*)$ (see Table 2). The independent variables are a zero rebate spread dummy that equals 1 if the firm has a zero rebate spread that day and 0 otherwise, the rebate spread for the firm that day (Reb), and the adjusted rebate spread for the firm that day (Reb^A), which is the average expected rebate rate spread over the life of the option using the 3-state AR(1) model estimated in Table 4. Panel B reports multivariate regressions of the stock price ratio on the rebate spread dummy, the rebate spread and 8 additional variables: (1) the percentage bid-ask spread averaged across the call and put, (2) the daily volume averaged across the call and put (divided by 100), (3) the open interest averaged across the call and put (divided by 1000), (4) the implied volatility of the call option, (5) the natural log of the average daily dollar volume on the stock over the prior 3 months (divided by the mean across all dates and stocks), (6) the ratio of open interest on the put to open interest on the call (divided by 10), (7) the moneyness of the options (100*ln(S/K)), and (8) the expiration of the option in years. The last column reports the standard deviation of these variables and the dependent variable. Standard errors are in parentheses.

Panel A: Rebate rate spread

	Sample	Const	Dummy	Reb	Reb^A	Rsq	Obs
Model 1	Reb<0	0.228 [a]		-0.241 [a]		0.108	24542
		(0.044)		(0.030)			
Model 2	Reb<0	-0.278 [a]			-2.746 [a]	0.097	24542
		(0.070)			(0.258)		
Model 3	All	0.228 [a]	-0.068 [c]	-0.241 [a]		0.074	80614
		(0.038)	(0.040)	(0.026)			
Model 4	All	-0.023 [a]			-2.25 [a]	0.065	80614
		(0.021)			(0.153)		

Table 3 (continued)

Panel B: Regressions with control variables

Model	**1**	**2**	**3**	**4**	**5**	**6**	**STD**
Sample	**All**	**All**	**All**	**Reb < 0**	**Reb < 0**	**Reb < 0**	
Dependent variable			**Unadjusted stock price ratio**				1.456
Constant	0.228 [a]	1.666 [a]	1.208 [a]	0.228 [a]	0.550	-0.353	
	(0.038)	(0.275)	(0.243)	(0.04)	(0.654)	(0.575)	
Rebate dummy	-0.068 [c]		-0.224 [a]				0.455
	(0.040)		(0.040)				
Rebate spread	-0.241 [a]		-0.249 [a]	-0.241 [a]		-0.258 [a]	1.663
	(0.026)		(0.032)	(0.03)		(0.037)	
Option spread		-0.032 [a]	-0.025 [a]		-0.018 [c]	-0.022 [b]	5.243
		(0.004)	(0.004)		(0.011)	(0.010)	
Option volume		0.006	0.005		0.085	0.073	1.184
		(0.007)	(0.005)		(0.060)	(0.047)	
Open interest		-0.022 [a]	-0.027 [a]		0.119	0.044	1.481
		(0.006)	(0.004)		(0.108)	(0.068)	
Implied volatility		-0.819 [a]	-1.235 [a]		-1.429 [a]	-1.727 [a]	0.245
		(0.076)	(0.067)		(0.174)	(0.170)	
Stock volume		-0.478 [b]	0.297		1.197 [b]	2.037 [a]	0.103
		(0.236)	(0.200)		(0.607)	(0.519)	
Open interest ratio		0.005 [b]	0.004		0.000	-0.002	2.319
		(0.002)	(0.003)		(0.006)	(0.007)	
Ln(S/K) (%)		-0.004 [a]	-0.003 [a]		-0.006 [b]	-0.005 [c]	4.670
		(0.001)	(0.001)		(0.003)	(0.003)	
Expiration (years)		-0.054	-0.082		0.520 [b]	0.499 [b]	0.071
		(0.094)	(0.089)		(0.238)	(0.223)	
Rsq	0.074	0.023	0.119	0.108	0.040	0.181	
Obs	80,614	67,149	67,149	24,542	19,625	19,625	

[a] - Significant at the 1% level
[b] - Significant at the 5% level
[c] - Significant at the 10% level

Table 4: Distribution and Time Series Model of Rebate Rate Spreads

The table reports the cross-section and time series properties of the rebate rate spreads for the stocks in the at-the-money, intermediate maturity sample (see Table 1B). The analysis is done on the rebate spread, which is the difference between the actual rebate rate on a stock and the rebate rate on "cold stocks" that day. Panel A provides descriptive statistics on the distribution of the rebate spread for the entire sample. Panel B reports the 1-period transition probabilities between zero and two negative rebate rate spread states. Panel C reports the conditional means in period *t+1* given the state in period *t*. Panel D reports estimates of an AR(1) model for rebate spreads conditional on spreads remaining in the same state (standard errors are in parentheses).

Panel A: Distribution of rebate rate spreads

Range	Obs	Mean	Median	5pct	95pct
Reb=0	56072	0	0	0	0
-0.5<Reb<0	12590	-0.13	-0.06	-0.43	-0.01
Reb<=-0.5	11952	-3.09	-2.07	-7.19	-0.58

Panel B: Transition probabilities between rebate spread states

Period			*t+1*	
		Reb=0	**-0.5<Reb<0**	**Reb<=-0.5**
	Reb=0	96.07	3.336	0.594
t	**-0.5<Reb<0**	15.205	77.79	7.005
	Reb<=-0.5	2.964	8.456	88.58

Panel C: Means of period *t+1* rebate spreads per state conditioned on period *t* state

Period			*t+1*	
	State(t)	**Reb=0**	**-0.5<Reb<0**	**Reb<=-0.5**
	Reb=0		-0.06	-2.442
t	**-0.5<Reb<0**	0		-0.998
	Reb<=-0.5	0	-0.261	

Table 4 (continued)

Panel D: AR(1) model for of negative rebate spreads within states

State	Const	AR(1)	R-sq	Obs
-0.5<Reb<0	-0.031 [a]	0.783 [a]	0.601	8073
	(0.001)	(0.007)		
Reb<=-0.5	-0.666 [a]	0.796 [a]	0.639	8548
	(0.032)	(0.006)		

[a] - Significant at the 1% level

Table 5: Frequency of Put-Call Parity Violations After Transaction Costs

The table reports the distribution of put-call parity of violations (in percent) after accounting for transaction costs in the options market for the at-the-money, intermediate maturity sample (see Table 1B). There are a total of 80,614 observations, of which 24,542 have negative rebate rate spreads. S^S is the lower bound on the stock price as derived from put-call parity (the implied short stock price), S^M is the stock price as derived from put-call parity when all option trades are traded at the midpoint, and S^L is the upper bound on the stock price as derived form put-call parity (the implied long stock price). In Panel A we use the observed stock price S, while in Panel B we use the stock price adjusted for the rebate rate cost over the life of the option (S^A), using the 2-state AR(1) model estimated in Table 4. The three test statistics test: (1) & (2) whether the probability the stock price exceeds the upper bound is equal to the probability that the stock price is less than the lower bound for zero and negative rebate rate spread stocks, and (3) whether the probability of exceeding the upper bound is equal across zero and negative rebate rate spread stocks. The test statistics have an asymptotic N(0,1) distribution under the null hypotheses.

Panel A: Unadjusted stock price

	$S<S^S$	$S^S<=S<S^M$	$S^M<=S<=S^L$	$S>S^L$
All	2.73	32.17	52.87	12.23
Reb=0	2.77	34.06	54.13	9.04
Reb<0	2.65	27.85	49.99	19.51

Test	Stat	P- value
$Pr(S<S^S\|Reb=0)=Pr(S>S^L\|Reb=0)$	18.91	0.00
$Pr(S<S^S\|Reb<0)=Pr(S>S^L\|Reb<0)$	17.90	0.00
$Pr(S>S^L\|Reb=0)=Pr(S>S^L\|Reb<0)$	10.66	0.00

Panel B: Stock price adjusted for rebate rate cost

	$S<S^S$	$S^S<=S<S^M$	$S^M<=S<=S^L$	$S>S^L$
All	3.56	39.15	47.70	9.59
Reb=0	3.21	38.75	50.21	7.82
Reb<0	4.36	40.05	41.96	13.63

	Stat	P- value
$Pr(S<S^S\|Reb=0)=Pr(S>S^L\|Reb=0)$	15.18	0.00
$Pr(S<S^S\|Reb<0)=Pr(S>S^L\|Reb<0)$	11.68	0.00
$Pr(S>S^L\|Reb=0)=Pr(S>S^L\|Reb<0)$	7.08	0.00

Table 6: Put-Call Parity and Option Expiration

The table reports the distribution of the ratio $R \equiv 100\ln(S/S^{*})$ for at-the-money, short (30 to 90 days), intermediate (91 to 181 days) and long (182 to 365 days) maturity options (see Table 2). The four test statistics are described in Table 2.

	Short			Intermediate			Long		
	All	**Reb=0**	**Reb<0**	**All**	**Reb=0**	**Reb<0**	**All**	**Reb=0**	**Reb<0**
Obs	75771	52439	23332	80614	56072	24542	32652	22891	9761
Mean	0.21	0.14	0.37	0.3	0.16	0.61	0.38	0.17	0.86
Percentiles									
1	-2.50	-2.49	-2.51	-2.93	-2.87	-3.04	-2.90	-2.88	-2.91
5	-1.03	-1.01	-1.09	-1.22	-1.19	-1.27	-1.13	-1.12	-1.15
10	-0.60	-0.58	-0.62	-0.68	-0.67	-0.69	-0.66	-0.67	-0.62
25	-0.14	-0.14	-0.13	-0.16	-0.18	-0.12	-0.18	-0.21	-0.08
50	0.16	0.13	0.24	0.20	0.16	0.35	0.22	0.15	0.46
75	0.51	0.44	0.70	0.65	0.53	1.02	0.69	0.53	1.31
90	1.03	0.88	1.40	1.33	1.04	2.04	1.54	1.04	2.70
95	1.53	1.28	2.12	1.97	1.49	2.97	2.36	1.56	4.01
99	3.34	2.54	4.85	4.42	2.82	7.68	5.37	2.97	9.07
R<0(%)	35.21	36.41	32.52	34.9	36.83	30.5	35.49	38.51	28.4
R>0(%)	64.79	63.59	67.48	65.1	63.17	69.5	64.51	61.49	71.6
Test		**Stat**	**P- value**		**Stat**	**P- value**		**Stat**	**P- value**
E[R|Reb=0]=E[R|Reb<0]		8.26	0.00		9.08	0.00		9.72	0.00
Pr(R>0|Reb=0)=50%		43.31	0.00		28.92	0.00		16.79	0.00
Pr(R>0|Reb<0)=50%		30.92	0.00		25.92	0.00		22.42	0.00
Pr(R>0|Reb=0)=Pr(R>0|Reb<0)		6.02	0.00		7.19	0.00		8.56	0.00

Table 7: Structural Change

Panel A reports the distribution of the ratio $R \equiv 100\ln(S/S^*)$ (see Table 2) for two separate subperiods for at-the-money, intermediate maturity options (for negative rebate rate spread stocks only). The sample is divided by the technology crash into the subperiods July 1999 to February 2000 and May 2000 to November 2001. The two test statistics test for equality of means and the percentage of stocks with ratios greater than 0 across the two subperiods. The test statistics have an asymptotic N(0,1) distribution under the null hypotheses. Panel B reports regressions of R on the rebate rate spread for negative rebate spread stocks for the 2 subperiods. The test statistic tests the equality of the coefficients on the rebate spread across the subperiods. Standard errors are in parentheses.

Panel A: Distribution of unadjusted stock price ratios

	Mean	Median	R>0(%)	Obs
7/99-2/00	0.687	0.490	74.151	7304
5/00-1/01	0.561	0.281	67.017	15490
Stat	1.449		4.973	
P-value	0.074		0.00	

Panel B: Regressions

Sample	Const	Reb	Rsq	Obs
7/99-2/00	0.235 [a]	-0.313 [a]	0.11	7304
	(0.053)	(0.038)		
5/00-1/01	0.193 [a]	-0.234 [a]	0.12	15490
	(0.053)	(0.037)		
Stat		1.479 [a]		
P-value		0.070		

[a] - Significant at the 1% level

Table 8: Stock Return Conditional Moments and Regressions

Panel A reports the cross-sectional means and standard deviations of industry adjusted cumulative returns on stocks over the life of the options conditional on various values of the rebate rate spread and the unadjusted stock price ratio $R \equiv 100\ln(S/S^*)$ (see Table 2). In each case, the test statistic tests whether the mean return equals zero. Panel B reports linear regressions of stock returns on rebate spreads and unadjusted stock price ratios. The dependent variable is the industry adjusted cumulative return on the stock over the life of the option. The independent variables are a zero rebate spread dummy that is equal to 1 if the firm has a zero rebate spread that day and 0 otherwise, the rebate spread for the firm that day (Reb), and the stock price ratio $R \equiv 100\ln(S/S^*)$. All regressions have 67,545 observations. Standard errors are in parentheses.

Panel A: Conditional moments

Filter	Obs	Mean	StdDev	Stat	P-value
Reb=0%	47555	0.698	39.645	1.085	0.861
Reb<0%	19990	-7.077	48.699	-5.989	0.000
Reb<-0.5%	9513	-9.962	50.262	-5.902	0.000
R<0%	23707	0.133	41.700	0.192	0.576
R>0%	43838	-2.542	43.162	-3.808	0.000
R>1%	9854	-4.489	47.285	-3.945	0.000
Reb<0%, R>0%	13822	-8.091	49.020	-6.312	0.000
Reb<-0.5%, R>0%	7001	-11.213	50.891	-6.086	0.000
Reb<0%, R>1%	5011	-9.333	50.057	-5.084	0.000
Reb<-0.5%, R>1%	3519	-12.567	51.389	-5.322	0.000

Panel B: Regressions

	Const	Dummy	Reb	Reb^A	R	Rsq
Model 1	-1.245 [b]				-1.278	0.002
	(0.610)				(0.293)	
Model 2	-5.447 [a]	6.145 [a]	1.04 [b]			0.008
	(1.276)	(1.365)	(0.426)			
Model 3	-5.317 [a]	6.128 [a]	0.848 [b]		-0.739	0.009
	(1.279)	(1.366)	(0.425)		(0.278)	
Model 4	1.403 [c]			21.746 [a]		0.008
	(0.764)			(4.033)		
Model 5	1.38 [c]			20.294 [a]	-0.636	0.008
	(0.763)			(3.992)	(0.291)	

[a] - Significant at the 1% level
[b] - Significant at the 5% level
[c] - Significant at the 10% level

Table 9: Portfolio Returns

The table reports returns characteristics of portfolios formed based on trading signals relating to the rebate spread and the unadjusted stock price ratio $R \equiv 100\ln(S/S^*)$ (see Table 2). All portfolios start on July 1999 and close on February 2002 for a total of 666 trading days. The portfolios have zero net investment and stocks are equally weighted each day. All portfolios short stocks with the relevant signal and go long an equal amount in a matched industry portfolio. Daily return is the average daily return on the portfolio; daily net return is the average daily return, net of the daily borrowing cost(rebate spread); STD net return is the daily standard deviation of the return on the portfolio; short obs is the average number of firms in the short portfolio per day. Panel B reports the intercept of a regression of daily portfolio returns and the Fama French 3-factor model. Gross α is the return on the portfolio. Net α is net of rebate cost on the short position. t-stat is in parenthesis).

Panel A: Portfolio daily-return characteristics.

Portfolio	Filter	Daily gross return	Daily net return	STD net return	Short obs
1	Reb<-0.5%	0.066% [c]	0.057%	1.00%	221
2	Reb<-1.0%	0.092% [b]	0.081% [b]	1.01%	167
3	R>0%	0.034%	0.030%	0.81%	318
4	R>1%	0.094% [b]	0.085% [b]	0.95%	90
5	Reb<-0.5% and R>0%	0.113% [a]	0.100% [b]	1.05%	93

Panel B: Intercept(α) of FF 3 factor model of daily portfolio return

Portfolio	Filter	Gross α	Net α
1	Reb<-0.5%	0.042% [c]	0.033%
		(1.79)	(1.41)
2	Reb<-1.0%	0.074% [a]	0.063% [b]
		(2.83)	(2.41)
3	R>0%	0.010%	0.006%
		(0.59)	(0.37)
4	R>1%	0.077% [a]	0.068% [b]
		(2.86)	(2.51)
5	Reb<-0.5% and R>0%	0.090% [a]	0.077% [a]
		(3.22)	(2.76)

[a] - Significant at the 1% level
[b] - Significant at the 5% level
[c] - Significant at the 10% level

Figure 1: Stock Price Ratios and Maturity

The figure shows the fitted stock price ratio from regressions for short, intermediate and long maturity at-the-money options on the rebate rate spread. The sample period is July 1999 to November 2001, and Table 6 reports information on the maturity-sorted samples.

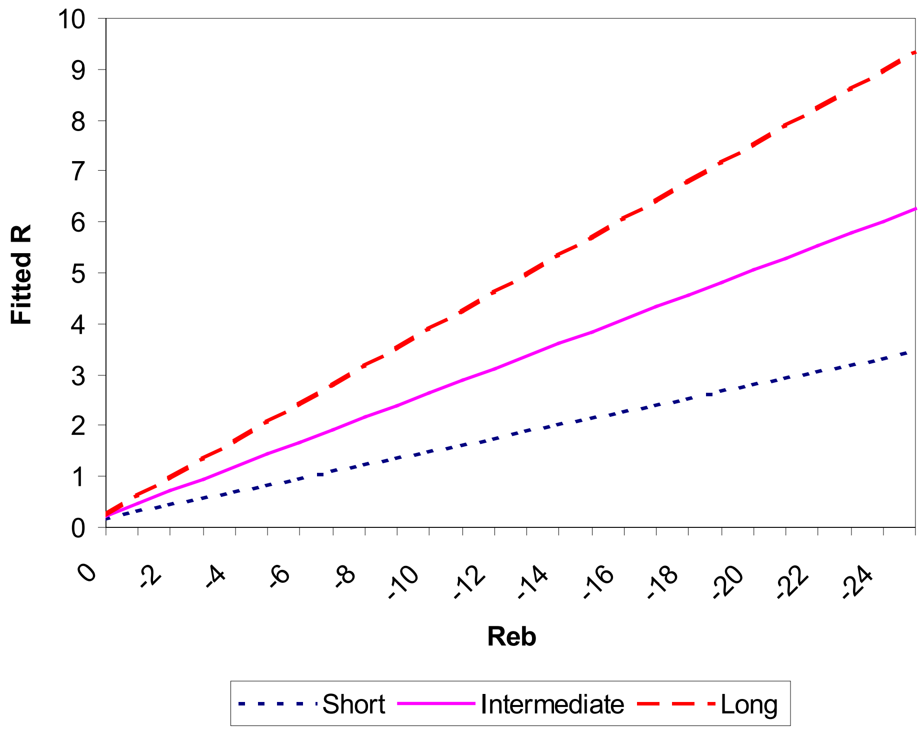

Figure 2: Stock Price Ratios and PE Ratios Over Time

The figure shows the median stock price *R* for zero and negative rebate rate spread stocks for the at-the-money, intermediate maturity sample (left axis) and the average PE ratio of the S&P500 (right axis) on a quarterly basis. The sample period is July 1999 to November 2001.

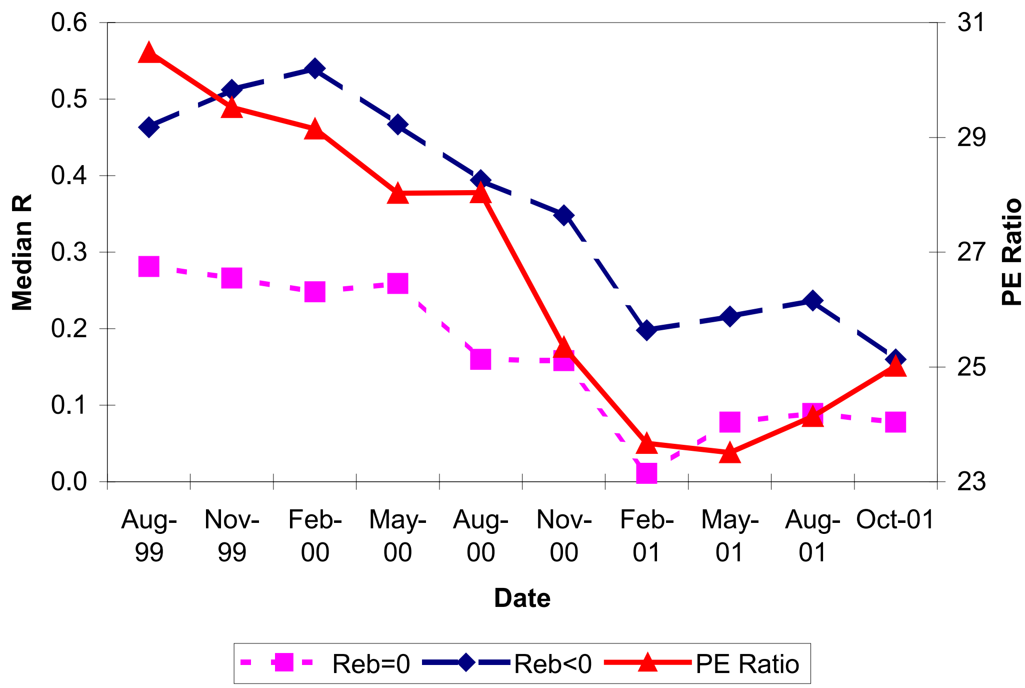

Figure 3: Portfolio Returns

The figure shows cumulative portfolio returns over the July 1999 to February 2002 period for three strategies that go short stocks based on rebate rate spread and stock price ratio signals and go long the corresponding industry portfolios. The returns are for portfolios 1, 3 and 5 from Table 9. Returns are net of shorting costs as measured by the rebate rate spread.