12-2020

Is the synthetic stock price really lower than actual price?

Jianfeng HU
Singapore Management University, JIANFENGHU@smu.edu.sg

Is the Synthetic Stock Price Really Lower Than Actual Price? *

Jianfeng Hu †

Lee Kong Chian School of Business, Singapore Management University

Abstract

Conventional wisdom suggests synthetic stock prices are lower than actual prices due to short-sale constraints and voting premiums. This study finds that such underpricing of the synthetic mid quote disappears if arbitrageurs face security borrowing costs. The synthetic spread predominantly contains the actual spread. Synthetic stock overpricing is as common as underpricing but the former is more persistent and more profitable. The difference between synthetic and actual quotes is significantly affected by options market makers' hedging costs and investors' demand for leverage.

JEL Classification: C13, C61, D82, G14.

Keywords: Options; law of one price; put-call parity; arbitrage; short selling.

*I would like to thank Gennaro Bernile, Ekkehart Boehmer, Jin-Chuan Duan, Fangjian Fu, Nicolae Garleanu, Michael Hofmann, Dashan Huang, Weikai Li, Kian Guan Lim, Roger Loh, Chenghu Ma, Roni Michaely, Dmitriy Muravyev, Melissa Prado, Paul Schultz, Melvyn Teo, Jun Tu, Chishen Wei, Liuren Wu, Bohui Zhang, Chu Zhang, and the seminar participants at Chinese University of Hong Kong (Shenzhen), NYU Shanghai, Singapore Management University, Zhejiang University, and 2018 Annual Conference of Canadian Derivatives Institute for comments. The author is grateful to the financial support from the Ministry of Education of Singapore. All remaining errors are mine.

†Lee Kong Chian School of Business, Singapore Management University, 50 Stamford Road, Room 4044, Singapore 178899. Phone: (+65) 6808-5477, Fax: (+65) 6808-0427, Email: jianfenghu@smu.edu.sg.

1. Introduction

A synthetic stock created using options should have the same price as the actual stock according to the law of one price. This result is known as the put-call parity for European options as in Stoll (1969) and extended by Merton (1973) for American options. A long list of studies examine whether the put-call parity holds in reality.[1] Several recent studies suggest that synthetic stocks are underpriced due to short-sale constraints on the underlying stocks (Ofek, Richardson, and Whitelaw, 2004) and value of voting (Kalay, Karakas, and Pant, 2014).

In this study, I use aftermarket data from Option Metrics, CRSP, and Markit between 2007 and 2012 to construct synthetic bid and ask prices for common stocks in the US. Similar to Ofek et al. (2004), Battalio and Shultz (2006), Muravyev, Pearson, and Broussard (2013), and many others, I adjust for options early exercise premiums and expected dividends based on the put-call parity. Trading synthetic stocks does not require investors to participate in the security lending market. However, this may not be the case for investors in the cash market. For example, a short seller in the stock market needs to borrow shares and pay a fee to the lender. Likewise, a stock owner can potentially lend the shares out to earn the fee. These security borrowing/lending fees can affect the net costs of trading actual stocks and potentially distort the put-call parity. To explicitly account for this friction arising from transaction costs, I assume the marginal investor is an arbitrageur in the main analysis. I then calculate the cash bid price by deducting the security borrowing fee from the

[1] Gould and Galai (1974) find frequent deviation from the parity in the over-the-counter market between 1967 and 1969. Klemkosky and Resnick (1979) adjust for dividends in empirical tests of the parity and find the arbitrage opportunities and profits decrease. Klemkosky and Resnick (1980) find that trading costs and delay in implementation for arbitragers further excludes violation of the parity. Phillips and Smith (1980) attribute many seemingly arbitrage opportunities to transaction costs of the bid-ask spread. Kamara and Miller (1995) find the violation is less frequent for European style index options.

observed national best bid price because the arbitrageur needs to borrow stocks to sell. When the arbitrageur trades at the ask and purchases the stock, I deduct only a probability-adjusted lending fee because stock owners may not always earn an income from lending the shares they have, as noted by Atmaz and Basak (2019).[2]

The comparison between synthetic and cash prices yields the following results. First of all, underpricing of synthetic stocks disappears once security borrowing costs are included in the analysis. During my sample period, the synthetic mid quote is slightly lower than the actual mid quote with an average price ratio of 99.98%. The indicated underpricing of 2 basis points is already remarkably smaller in this recent sample period when both markets close at the same time. Moreover, after adjusting security borrowing costs in cash quotes, the synthetic mid quote is exactly the same as the cash mid quote on average. Therefore, the evidence contradicts systematic underpricing of synthetic stocks in prior literature.

Secondly, I find that the synthetic ask is higher than the cash ask with a price premium at about 1% on average. However, the synthetic bid is lower than the cash bid with a price discount of the same magnitude. Although there is no systematic difference between mid quotes on the two markets, synthetic spreads on average are wider than actual spreads. In fact, more than 95% of the time, the actual bid and ask prices are contained by the synthetic quote prices. This evidence suggests that investors almost always face inferior prices in the synthetic market regardless of the direction of trading. Moreover, this pattern of quotes on the two markets is the most persistent among all possible quote patterns as the estimated Markov chain suggests. Collectively, the results

[2] Alternative assumptions regarding the probability of paying/earning the security borrowing fees yield qualitatively the same results.

suggest that the difference between synthetic and actual stock prices does not reside in the mid quote but rather the size of bid-ask spreads.

Thirdly, the total cross-market arbitrage opportunities after accounting for transaction costs occur in less than 2% of the stock-day observations. More importantly, the likelihood of an arbitrage opportunity due to synthetic underpricing is almost the same as the likelihood of the opposite type of arbitrage due to synthetic overpricing. However, arbitrage opportunities due to overpriced synthetic stocks are more persistent and exhibiting higher arbitrage profits.

The comparison result in this study clearly refutes systematic underpricing of synthetic stocks. However, why are synthetic prices always worse than cash prices? One possibility is that investors rarely trade synthetic stocks and wider spreads of synthetic stocks just reflect additive effects of trading costs of two option trades. However, there is evidence that synthetic stock trading is commonly used by options traders despite obvious disadvantages in the spread. For example, in monthly retail investors' position data in the U.S. studied by Odean (1998), about 6% of options traders had synthetic stock positions between 1991 and 1996. In Korea's KOSPI 200 options market between 2010 and 2014 studied by Hu, Kirilova, Park, and Ryu (2020), synthetic stocks are used by 37% of domestic institution accounts, 10% of domestic retail accounts, and 31% of foreign institution accounts. In the second part of the paper, I borrow several theories in the literature to investigate determinants of synthetic stock spread.

The first mechanism considered is options market makers' hedging costs. Because delta hedging in the underlying market is costly, options market makers may transfer the hedging costs to options traders by quoting wider spreads. Therefore, the synthetic bid and ask also become wider as the hedging costs, measured by the underlying bid-ask spread, increases. Moreover, because hedging may be imperfect, options market makers may quote a risk premium in synthetic prices for unhedgable risk measured by volatility of implied volatility.

The second determinant of price discrepancy examined in this study is investors' preference for leverage. Galeanau and Pedersen (2011) show that margin difference can distort prices of securities with the same future payoff in credit markets.[3] Similarly, the leverage preference could potentially affect the price of an asset providing higher leverage to equity investors. The capital requirement to trade synthetic stocks is usually less than a quarter of what is needed to trade underlying stocks based on the margin requirements posted by equity options exchanges in the US. If it is less capital demanding to trade synthetic stocks, it is possible that buyers are willing to pay a premium for synthetic stocks and sellers are willing to accept a discount. Because institutional investors are less financially constrained, I measure the (inverse) demand for leverage using the proportion of shares held by institutions.

The last channel is concentrated informed trading and higher adverse selection costs in the options market. As Black (1975) note, informed traders can prefer the options market for higher leverage or to get around short-sale constraints. Supporting evidence exists in e.g. Pan and Poteshman (2006), Hu (2014), and Ge, Lin, Pearson (2016). Higher information risk in options trading can lead to wider spreads as options market makers adjust for adverse selection costs in the quotes. In the empirical analysis, adverse selection costs are proxied by the absolute order

[3]See theoretical analysis of interaction between leverage and asset prices in, e.g. Gromb and Vayanos (2002, 2018), Fostel and Geanakoplos (2003), Brunnermeier and Pedersen (2009), Garleanu and Pedersen (2011), and Rytchkov (2014). Empirical evidence of such pricing effect can be found in, e.g., Frazzini and Pedersen (2014) and Jiang (2018) for the cross-section of equity, Garleanu and Pedersen (2011) for the credit market, Mitchell and Pulvino (2012) for hedge fund strategies on corporate securities, Hu, Pan, and Wang (2013) for hedge fund returns, and Boguth and Smutin (2018) for mutual fund returns.

imbalance in the two markets following an approximation to the probability of informed trading derived by Easley, Engle, O'Hara, and Wu (2008).

To examine determinants of the price difference between synthetic and actual stocks, I construct relative ask and bid by dividing the synthetic ask and bid using the cash ask and bid. Then I separately regress relative ask and bid on the aforementioned explanatory variables using Fama-MacBeth (1973) regressions. The results clearly support the first two channels. Specifically, consistent with higher hedging costs leading to wider synthetic spreads, both underlying spread and volatility of implied volatility increase synthetic ask relative to actual ask but decrease synthetic bid relative to actual bid. Also consistent with investors' preference of leverage driving asset prices, institutional ownership is negatively associated with the relative ask and positively with the relative bid, suggesting that capital constraint of the representative investor can make synthetic stocks more attractive, resulting in seemingly inferior synthetic prices. The results are less clear regarding the information story. The absolute stock order imbalance significantly reduces the relative spread by making the relative ask lower and relative bid higher, consistent with higher information risk in stock trading resulting in wider stock spreads. However, the absolute options order imbalance does not have a robust relation with the relative ask or bid. In the tests when the relations are statistically significant, information risk in options trading also narrows the spread gap rather than widens the gap. Therefore, these tests fail in providing conclusive evidence regarding the role of adverse selection costs in synthetic stock pricing.

The paper contributes to the finance literature in several ways. First, I show that the synthetic mid quote is not systematically lower than the actual mid quote. This result contrasts conclusions in prior studies such as Ofek et al. (2004) and Kalay, et al. (2014). I find that the previous results are largely driven by asynchronous trading in the past and imperfection in adjusting for security borrowing costs when researchers compare stock prices in the two markets.

Second, I find that synthetic quotes differ from actual quotes mainly in the size of the spread rather than the midpoint location. Synthetic stocks usually have wider spreads and it is more costly to trade synthetic stocks for price takers. This result exists in the large cross-section of all stocks with options and is consistent with intraday findings from restricted samples by Battlio and Schultz (2006) and Muravyev, Pearson, and Broussard (2013). Moreover, I also examine the determinants of such quote differences and uncover significant effects from both the supply (hedging costs) and demand sides (leverage). Therefore, seemingly inferior synthetic pricing can be an equilibrium outcome. These results are novel to the literature and relate to the growing literature on pricing liquidity and leverage. In a recent study, Goncalves-Pinto et al. (2020) find that options quotes lag stock quotes in response to price pressures, leading to significant return predictability from options prices when subsequent stock price reversal happens. The results in this study provide potential reasons to such stickiness in options prices because the price difference across the two markets does not often induce arbitrage opportunities.

Finally, I propose an augmented put-call parity adjusting for security borrowing costs. This is one of the first papers noting the importance of security lending fees in derivative pricing. Muravyev, Pearson, and Pollet (2018) find that the option-implied borrowing cost is close to the actual borrowing cost. Atmaz and Basak (2019) extend the Black-Scholes-Merton option pricing framework using security borrowing costs and analyze option prices during the short-selling ban in 2008. This study differs from the aforementioned work by testing the augmented put-call parity instead of analyzing model-dependent option prices.

The rest of the paper is organized as follows. Section 2 describes the data, sample selection, and explains how main variables are constructed. Section 3 reports the empirical results of the analysis. Section 4 concludes.

2. Data

2.1. Sample selection

I obtain daily close bid and ask prices of options and underlying stocks from Option Metrics and CRSP, respectively. I acquire the security lending fee from Markit for common stocks in the US between 2007 and 2012, as well as the total loanable shares and outstanding shares on loan. To be included in the sample, each stock-day observation must have non-missing close bid-ask prices in both CRSP and Option Metrics, and have borrowing cost information in Markit. The study focuses on common stocks with CRSP security code of 10 and 11. After merging the databases, there are 3,309,575 daily observations. To avoid impact of penny stocks, 391,752 observations with the underlying stock price below 5 dollars are excluded. Also excluded are 12,609 observations with stock distributions other than ordinary dividend because options trading around these corporate events can differ from normal days. Other than deleting data errors such as loanable shares greater than 100%, following Ofek, Richardson, and Whitelaw (2004), I also exclude observations with negative security lending fees. This treatment further removes 125 observations. I use only the closest-to-the-money pair of call and put options with the strike price to spot price ratio between 0.95 and 1.05, non-zero open interest, and the maturity of 10 to 40 days because such options have the best liquidity and smallest early exercise premiums, and are less affected by non-normalities of the asset price dynamics.[4] There are 2,087,891 observations left after this procedure. To avoid bad quotes, I exclude any locked (bid = ask) or crossed (bid $>$ ask) quotes of the underlying stock, call and put options, and require the bid price to be non-zero, leaving 1,934,827 observations. Finally, to mitigate the impact of outliers, I exclude 20,026 observations that have the ask greater than 10 times the bid price and the bid-ask spread greater than one dollar on either the call or put option. The final sample contains 1,914,801 stock-day observations. Table 1 describes this sample. The number of observations and unique number of stocks are relatively stable over individual years with around 2300 unique stocks and 3 million stock-day observations every year. Table 1 also lists the average daily stock and options trading volumes and the options open interest. It is clear that options market liquidity has significantly improved over time with growing average daily trading volume while the average stock trading volume peaks in the financial crisis in 2008 and then gradually decreases afterwards.

(Table 1 about here)

[4]Using alternative options contracts also yields qualitatively the same results although there are slightly more occasions when the no-arbitrage bounds are violated.

2.2. Synthetic stock prices

Following Battalio and Schultz (2006) and Muravyev, Pearson, and Broussard (2013), I calculate the synthetic stock bid (bid_i) and ask (ask_i) prices as follows:

$$ask_i = (Ask\_Call - EEP\_Call) - (Bid\_Put - EEP\_Put) + PV(K) + PV(Div), \tag{1}$$

$$bid_i = (Bid\_Call - EEP\_Call) - (Ask\_Put - EEP\_Put) + PV(K) + PV(Div), \tag{2}$$

where Ask_Call and Bid_Call are the ask and bid prices of the call option, Ask_Put and Bid_Put are the ask and bid prices of the put option, EEP_Call and EEP_Put are the early exercise premiums of call and put options, $PV(K)$ and $PV(Div)$ are the present values of the strike price and the expected dividend. The early exercise premium is calculated as the difference between the actual price and the Black-Scholes model implied European option price using implied volatilities in Option Metrics. The expected dividend is the announced future dividend before the options expiration.

2.3. Adjusting borrowing costs in actual stock prices

A price taker pays the ask price to buy stocks. This long stock position can be liquidated at any time. However, the synthetic stock will expire when the options expire. Without loss of generality, the analysis assumes the long position will be held until the options maturity when comparing synthetic and actual ask prices. During this investment period, the investor may lend the stock to earn extra income. Stock lending is typically done through brokers in an over-the-counter market.[5]

[5] See D'Avolio (2002) for more details about this market.

Suppose that the borrowers of stocks pay a net lending fee ($lendingfee$) to the lender and the probability of lending is the same as the ratio of outstanding shares on loan to the total loanable shares ($utilization$), the net purchase cost for the actual stock is the following:

$$ask_a = ask * (1 - utilization * lendingfee * t * exp(-r * t)), \tag{3}$$

where *ask* is the original national best close ask price across all stock exchanges, r is the risk-free rate, and t is the time to expiration of the options used to construct the synthetic stock. In order to streamline the analysis on the net cost of security borrowing, I do not consider uncertainty from early recall of the shares on loan by the lender.

The bid price adjustment is more complicated depending on the seller's stock position. If the seller already has a long stock position (a stock owner), after selling the stock, the seller forgoes the expected actual income from lending the stock. If the seller does not have a stock position (an arbitrager), the total security lending cost must be deducted from the sales proceeds when calculating actual prices. Therefore, the borrowing-cost adjusted bid price is different for stock owners and arbitragers. Because cross-market price efficiency depends critically on arbitrage activities, this study focuses on the bid price for arbitragers defined as:

$$bid_a = bid * (1 - lendingfee * t' * exp(-r * t)), \tag{4}$$

where *bid* is the original national best close bid price across all exchanges, t' is the time between settlement of short sale and options maturity date, and the other variables are the same as defined previously.[6] The settlement date of short sale is used instead of the execution date because practically the short seller needs to deliver the stock only on the settlement day. This time lag between execution and settlement in the security lending market is usually 3 days. This choice of settlement lag, however, is not critical to the analysis as the results are largely the same without having the settlement lag.

3. Compare the synthetic and actual prices

To begin the analysis, I first compare the midpoint of bid and ask prices between synthetic and actual stocks in Table 2 similar to existing studies. Panel A shows that the ratio of synthetic mid quote and raw cash mid quote has an average of 99.975% with a standard deviation of 0.473%. The 2.5 basis points (bp) of price discount on the synthetic mid quote is smaller than the discount of about 20 bp in Ofek et al. (2004). This reduction of underpricing can result from synchronous trading of the two markets during my sample period as well as development in financial markets over time. In the extreme, the synthetic mid quote can be only about 75% of the actual mid quote or exceed 150% of the actual mid quote. After adjusting for borrowing costs, the ratio between synthetic mid quote and cash mid quote averages at 100.001%, indicating that the synthetic underpricing disappears completely in the price ratio. Panel A also reports descriptive statistics for the dollar difference and the effects of borrowing costs clearly exist here too. Without borrowing costs, the synthetic mid quote is lower than the actual quote by 66 cents on average. The price wedge reduces to less than 5 cents once the borrowing costs are considered.

[6] Using the bid price for stock owners generates largely the same conclusion in the analysis.

Panel B reports the percentage of observations having the synthetic midpoint above and below the actual midpoint in individual years as well as in the full sample. Without considering borrowing costs, the synthetic midpoint is above the actual midpoint for 44.75% of all stock-day observations in the sample. In other words, the synthetic mid quote is more likely to be lower than the actual mid quote with a frequency difference of 10.5%. Once the security borrowing costs are included in the analysis, however, the proportion of observations with higher synthetic mid quote increases to 47.83%, significantly reducing the imbalance between the two types of observations from 10.5% to 4.34%. The same pattern is present for all individual years except 2008, when significantly more observations have synthetic prices below the actual price. The anomaly in 2008 are consistent with previous findings for stocks under the SEC's short-selling ban in Battalio and Schultz (2011) and Grundy, Lim, and Verwijmeren (2012). However, I find that the effect is market-wide rather than confined to only stocks under the short-selling ban.

(Table 2 about here)

The results in Table 2 indicate that synthetic stocks have similar values to actual stocks at the mid quote prices. But most options traders are liquidity takers. Therefore, it is important to examine the bid and ask prices separately in addition to the mid quote. Table 3 examines the relative bid price similar to Table 2. Panel A shows that on average, the synthetic bid price is lower than the actual bid for an arbitrager with a discount of about one percent. The dollar difference on average is about 26 cents per share, equivalent to about one percent of the actual bid price. The extreme bid difference can exceed 30 dollars in both directions. The effect of borrowing cost is much smaller in this analysis of the relative bid than in the case of mid quote. Panel B of Table 3 shows that during the full sample period, 97.9% of the stock-day observations have the synthetic bid less than the actual bid even after adjusting for borrowing costs. This ratio is stable around 98% in individual years, and increases slightly if borrowing costs are not accounted for. During volatile periods in 2008 and 2009, there are more observations with the synthetic bid below the actual bid. Clearly, the bid price is lower in the synthetic market than the actual market.

(Table 3 about here)

Next I turn to the ask side in Table 4. Panel A shows that the average synthetic ask price is greater than the average actual ask price with a premium of about 1%. Even for unadjusted actual ask, the synthetic ask is about 25.1 cents higher on average. Including borrowing costs does not significantly change the result. The synthetic ask premium in this table is similar in magnitude to the synthetic bid discount in Table 3. Given that no penny stock is included in the sample, the large premium of the synthetic ask is surprising. In Panel B, I find that between 2007 and 2012, 97.67% of stock-day observations have the synthetic ask above the adjusted actual ask. Even without borrowing costs, 97.09% of observations still have higher synthetic ask prices. Similar pattern also exists in individual years. Surprisingly, in 2008 and 2009, the ratio does not decrease while more synthetic bids fall below the actual bid at the same time. Instead, the ratio rises above 98%. This increase cannot be explained by the short-selling ban or elevated short-selling difficulty during the financial crisis, suggesting room for other determinants of the price difference.

(Table 4 about here)

The results in Tables 3 and 4 suggest that price takers usually have better prices in the actual market than in the options market regardless of the direction of trades. I will further investigate why the synthetic prices can remain inferior in an equilibrium later.

4. Arbitrage opportunities

In this section, I examine potential cross-market arbitrage opportunities. Given two sets of bid and ask prices and no data error of crossed or locked spread in the same market, there are six possible scenarios as illustrated in Figure 1.

- Type A: Synthetic ask above actual ask, and synthetic bid below actual bid.
- Type B: Synthetic ask above actual ask, and synthetic bid between actual ask and actual bid.
- Type C: Synthetic ask between actual ask and actual bid, and synthetic bid below actual bid.
- Type D: Synthetic ask below actual ask, and synthetic bid above actual bid.
- Type E: Synthetic bid above actual ask.
- Type F: Synthetic ask below actual bid.

(Figure 1 about here)

Out of the six types, only Type E and Type F represent arbitrage opportunities. Type E arbitrage involves selling at the synthetic bid and buying at the actual ask when the synthetic stock is overpriced relative to the actual stock. Type F arbitrage is the opposite. Panel A of Table 5 reports the frequency of each type of quote location using borrowing-adjusted actual prices in individual years as well as the full sample. Type A quotes clearly dominate the sample with 95.66% of observations in this category in the full sample. There is a marginal decrease in this ratio in the second half of the sample. Nonetheless, most of the time, the synthetic bid and ask prices contain the actual bid and ask. The next two types, B and C, have one spread partially entering the other but do not represent executable arbitrage opportunities. Each of these two types account for less than 1.5% of the observations. The least frequent type is Type D, which has the synthetic quote contained by the actual quote. There is only 0.1% of observations in this category and there is a clear declining trend over time. Finally, the Type E arbitrage opportunity occurs in 0.89% of observations and the Type F arbitrage in 0.82% of observations. There is no clear imbalance between the frequencies of these two types of arbitrage. Interestingly, both Type E and F arbitrage opportunities see some growth over time. To reconcile the finding with results in previous studies, Panel B uses the original actual bid and ask prices without security borrowing costs. Now the ratio of Type F arbitrage increases to 1.28% in the full sample and the ratio of Type E arbitrage decreases to 0.75%. But once the borrowing cost is included, this asymmetry disappears. Nonetheless, even without borrowing cost, Type A quotes exist for 95.5% of total observations, clearly representing an equilibrium result that is not well studied in the literature. These results suggest that cross-market arbitrage opportunities occur in less than 2% of stock-days in these markets, and most of the time, the synthetic quotes contain the actual quotes on both the ask and bid sides.

(Table 5 about here)

Table 6 reports the one-day Markov chain transition matrix estimated in the full sample. Regardless of the quote type on the previous day, the most likely state for the current quotes is always Type A as the estimated Type A probabilities in the first column are always the largest in each row. If the quote type is Type A, the same type occurs on the next day with a probability of 97.22%. For other quote types, they will become Type A with probabilities greater than 40% on the following day. The next largest probability in each row is then the same type as the previous day. However, for the no-arbitrage types B, C, and D, the tendency of remaining the same type is less than 13% and they switch to Type A with probabilities of at least 68%. The Type F arbitrage with underpriced synthetic stocks has a probability of 19.56% to remain as the same arbitrage type on the following day. But the Type E arbitrage with overpriced synthetic stocks is even more persistent with a probability of 37.98% to be the same type on the following day.

(Table 6 about here)

To understand how profitable the two types of arbitrage opportunities are, Panel A (B) of Table 7 reports the number of stock-days with Type E (F) arbitrage opportunities and average arbitrage profit per share. Looking at Type E first, Columns (1) and (2) show that there are 17,007 observations flagged in the full sample with an average arbitrage profit of 29.9 cents per share. There is a clear pattern of increasing number of arbitrage opportunities (possibly due to expansion of the options market) and decreasing average profits over time. To assess whether the arbitrage profit survives transaction costs, I assume an arbitrager pays commissions for 10 lots of trades in Columns (3) and (4) and for 1 lot only in Columns (5) and (6).[7] The commission per share

[7] I follow Barraclough and Whaley (2012) to use the concurrent broker quote for electronic trading by Charles

is reduced when the trading volume increases because of dilution in fixed cost. The number of arbitrage opportunities decreases after transaction costs are included. However, even with the highest transaction costs for only 1 lot of trade, there are still 2,784 observations under Type E arbitrage. Moreover, the average profit increases to 0.621 and 1.297 dollars per share when the commissions of 10 lots and 1 lot are considered, respectively. Turning to Type F arbitrage next, Panel B shows that there are 15,677 observations in this category with an average arbitrage profit of 4.9 cents per share. While the frequency of Type F is similar to that of Type E, the average profit is much lower. After transaction costs are included in the analysis, Type F arbitrage opportunities also become less frequent. With fees for 1 lot of trade, there are only 433 Type F arbitrage opportunities with an average profit of 0.411 dollar per share. The result suggests that arbitrage opportunities due to underpriced synthetics are more difficult to capture than those due to overpriced synthetics.

(Table 7 about here)

5. Determinants of relative prices

So far, the analysis has shown that the synthetic stock quote contains the actual quote most of the time and there are limited arbitrage opportunities across the two markets. A natural question is why the synthetic quotes are worse than actual quotes while the midpoints are the same. In the rest of the paper, I explore the following mechanisms as potential determinants of the relative prices.

Schwab to estimate the options and stock trading and options exercise costs. Specifically, the trading commission is 8.95 dollars for one stock trade regardless of the size of the trade, 8.95 dollars plus 75 cents per lot for an option trade, and 8.95 dollars for an order to exercise options. Under this fee structure, the total commission paid to trade 10 lots of shares involves one stock transaction, two options transactions, and one options exercise, amounting to 41.9 dollars, equivalent to a per share cost of 4.19 cents. To trade one lot of shares, the per-share cost is significantly higher at 28.35 cents because there is a large portion of fixed cost in the broker fee.

1. Hedging costs: From the market makers' viewpoint, the synthetic security can be more costly to quote because of the required delta hedging and imperfect hedge (Cetin, et al., 2006, Garleanu, Pedersen, and Poteshman, 2009, and Goyenko, Ornthanalai, and Tang, 2015). Therefore, market makers have an incentive to quote higher synthetic ask and lower synthetic bid than the actual prices. Three measures of hedging costs are used. The first is the underlying stock's percentage bid-ask spread (*Spread*) as the options market makers are likely to pay the stock spread when performing delta hedging. The second measure is stock return volatility calculated as the standard deviation of daily returns in the past 21 trading days, which correlates with the "pick-up" risk of market-making in Muravyev and Pearson (2020). The last measure is the standard deviation of average implied volatility (*Vol_ivol*) of at-the-money call and put options with 30 days to maturity in the past 21 business days using data from OptionMetrics. This volatility of implied volatility measures the remaining risk after delta hedging coming from either stochastic volatility or jumps.

2. Leverage: Capital constrained investors may prefer securities that provide higher leverage even if the cash flows are the same (Garleanu and Pedersen, 2011). During the sample period, trading synthetic stocks requires an investor to pay the full premium for the long leg of option and deposit into a margin account for the short leg. The total sales proceed of the short leg of option is also kept in the margin account before the position is closed.[8] Following the required margin rule, we calculate the actual capital needed to trade one share of a synthetic stock. On average, this number is about 24% of the actual price regardless of

[8] Details about the options trading margin can be found on options exchanges' website, e.g. at CBOE http://www.cboe.com/institutional/margin-and-escrow-receipts.

the direction of the trade.[9] Under Regulation T of the Federal Reserve Board, an investor can borrow up to 50% of the capital needed to trade actual stocks. Therefore, even after taking the maximum leverage on the actual stock, the synthetic stock still takes less than half the capital to trade. This difference in capital requirement implies that investors with capital constraints can achieve larger risk exposure in the synthetic market, making such securities more attractive. Therefore, it could lead to a price premium for buyers and a discount for sellers. This leverage-based explanation yields a testable hypothesis both in time series and in the cross-section. A direct measure of the leverage effect is to compare the capital requirement to trade synthetic and cash stocks. However, this measure can be mechanically correlated with the price ratio examined as the dependent variable because the margin requirement of synthetic stocks is derived using stock and option prices. There can also be concern that the price difference reverse causes the relative leverage. To circumvent the issue, I consider a proxy for capital constraint of the representative investor using institutional ownership (*Ownership*) at the end of the previous quarter in Thomson Reuters 13F database. The representative investor is more likely to be financially constrained for stocks with low institutional holding because retail investors usually have limited financing sources.

3. Adverse selection costs: The risk of trading with an informed investor can increase the bid-ask spread in market microstructure theories such as Glosten and Milgrom (1985) and Easley and O'Hara (1987). If the information risk differs in the two related markets, the one preferred by informed traders may see wider spreads. A long list of studies examine the lead-lag relation between the options and stock markets and there is clear evidence of

[9]Note that for short sellers of the actual stock, a deposit is also collected together with the sales proceed in a margin account.

informed trading in both markets (see, e.g. Easley, Srinivas, and O'Hara (1998) and Hu (2014)). If the options market has a higher concentration of informed traders, it is possible that the synthetic quote is wider. A recent study of Hu (2018) shows that the introduction of options leads to more intense trading by informed traders. To measure adverse selection in both markets, I use the absolute order imbalance as an approximation to the probability of informed trading following Easley et al. (2008). I follow Hu (2014) to calculate the options order imbalance as

$$OOI = \frac{\sum_{j=1}^{n} Dir_j \cdot delta_j \cdot size_j}{Num\_shares\_outstanding}, \tag{5}$$

where the numerate sums the imbalance of options delta volume across all options contracts on the same underlying stock. The pure stock market order imbalance is then

$$SOI = TOI - OOI = \frac{\sum_{j=1}^{N} Dir_j \cdot size_j}{Num\_shares\_outstanding} - OOI, \tag{6}$$

where TOI is the total stock order imbalance calculated as the net stock imbalance over the shares outstanding. The options tick data are obtained from Trade Alert LLC and the stock tick data from NYSE TAQ. Both options and stock trades are signed by the Lee and Ready (1991) algorithm. In particular, if a transaction is executed above (below) the prevailing quote midpoint, it is classified as buyer-initiated (seller-initiated). For those transacted at the mid quote, it is buyer-initiated (seller-initiated) if the trade price is higher (lower) than the last different trade price.

To examine the determinants of relative prices, I calculate a relative ask (bid) between the two markets as the synthetic ask (bid) divided by the borrowing-adjusted cash ask (bid) minus one. Then I regress the relative prices on the candidate variables described above using Fama-MacBeth (1973) regressions. The cross-sectional slope coefficients are first estimated every day and then averaged over time. To account for the serial correlation in the slope coefficients, Newey-West (1987) standard errors with six lags are used to calculate the t-statistics. Table 8 reports the results for the relative ask as the dependent variable with each category of explanatory variables are first examined separately and then altogether. In Column (1), I examine the effect of hedging costs. The coefficient of *Spread* is significantly positive with a t-statistic of 23.7, indicating that larger underlying spread boosts the relative ask price. Stochastic volatility also has a positive impact on the relative ask as the coefficient estimate has a t-statistic of 41.8. Because it is more costly for options market makers to hedge when the underlying spread is large or when the volatility of volatility is high, these results support the notion that hedging costs can make the synthetic stock ask higher relative to the actual ask. Column (2) investigates the leverage effect coming from options traders' demand. Institutional ownership, as a measure of inverse financing constraint, is negatively related to the relative ask with a t-statistic of -63.18, consistent with the prediction that the demand for leverage can lead to a higher synthetic ask price for buyers. Column (3) examines the impact of adverse selection. The absolute order imbalance in both the options and stock markets have negative coefficient estimates statistically significant at the 1% level. While adverse selection costs in the stock market are expected to increase the actual ask, hence reducing the relative ask, the negative relation between information risk in the options market and relative ask is inconsistent with the effect of adverse selection. Therefore, the overall effect of adverse selection is unclear in this test. Finally, in Column (4), I regress relative ask on all the explanatory variables at the same time. The results on all the variables are qualitatively the same as in the first three columns.

(Table 8 about here)

Next, I turn to the relative bid in Table 9, expecting the estimated coefficients to have opposite signs to those in Table 8. This is because the same factor driving synthetic ask higher should lead to lower synthetic and relative bid. The results in all the columns support this prediction. Specifically, both *Spread* and *Vol_ivol* are negatively related to the relative bid, suggesting that high hedging costs of options market makers reduce the synthetic bid relative to the actual bid. *Ownership* has a positive and significant coefficient, indicating that synthetic bid is higher when the representative investor is less financially constrained. This is consistent with sellers' demand for leverage drives the synthetic bid lower than the actual bid. Mirroring the results in Table 8, I also find that information risk in both the stock market and options market increases the relative bid. While the positive relation between adverse selection in stock trading and the relative bid is consistent with classical microstructure theories, the same effect from options trading imposes challenges to the theories.

In summary, the analysis in this section shows that wide synthetic bid-ask spread relative to the actual spread is mainly driven by options market makers' hedging costs and options traders' demand for leverage. Meanwhile, the information based mechanism has inconsistent effects empirically.

(Table 9 about here)

6. Conclusion

In this article, I analyze the price difference between synthetic stocks constructed using options and actual stocks after adjusting for security borrowing costs explicitly. The results show that contrary to the conventional wisdom that the synthetic price is lower than the cash price, in the sample of all common stocks with options between 2007 and 2012, the synthetic mid quote price is not systematically different from the mid quote in the cash market. However, the synthetic bid-ask spread usually contains the cash spread, suggesting the synthetic prices are inferior to cash prices for both buyers and sellers. This pattern exists for over 95% of stock-day observations. The arbitrage opportunity with overpriced synthetic stocks is as common as that with underpriced synthetic stocks, both at around 0.8% of the time. However, the arbitrage with overpriced synthetic stocks is more persistent for the same stock over time, and has a greater average profit.

Having documented the puzzle that synthetic stock traders always face worse prices than cash stock traders, the study investigates why this can be an equilibrium result. The regression analysis shows that the wide synthetic spread results from options market makers' hedging costs and options traders' demand for leverage. Specifically, the spread increases on both the ask and bid sides when the underlying spread is large, when the volatility of implied volatility in the options market are high, or when the institutional ownership of the underlying stock is low. Although adverse selection costs are important in the market microstructure literature in determining the spread, I fail to find consistent evidence supporting the same effect in synthetic pricing. Nonetheless, the explanations from both supply and demand sides uncovered potentially lead to an equilibrium result. It would therefore be interesting to develop derivative pricing models that take into account the hedging costs and demand for leverage at the same time. This article focuses on the comparison and explanation of the price difference between synthetic and cash stocks. For future research, it would be interesting to examine the asset pricing implications. There is a large literature on the lead-lag relation between derivative and underlying markets motivated by informed traders' choice of the trading venue. Given the impact of non-information related market frictions documented in this study, it is possible that the return predictability can root in dynamics of relative liquidity, options market makers' hedging costs, and investors' leverage demand too. I leave these questions to future studies.

Data Availability Statement

The data that support the findings of this study are available from OptionMetrics, Markit, Trade Alert, NYSE, and CRSP. Restrictions apply to the availability of these data, which were used under license for this study. Data are available from the author with the permission of OptionMetrics, Markit, Trade Alert, NYSE, and CRSP.

Reference

Atmaz, A., Basak, S., 2019. Option prices and costly short-selling. Journal of Financial Economics 134, 1-28.

Barraclough, K., Whaley, R., 2012. Early exercise of put options on stocks. Journal of Finance 67, 14231456.

Battalio, R., Shultz, P., 2006. Options and the Bubble. Journal of Finance 61, 2071-2102.

Battalio, R., Shultz, P., 2011. Regulatory Uncertainty and Market Liquidity: The 2008 Short Sale Ban's Impact on Equity Option Markets. Journal of Finance 66, 2013-2053.

Black, F., Scholes, M., 1973. The pricing of options and corporate liabilities. Journal of Political Economy 81, 637654.

Black, F., 1975. Fact and fantasy in the use of options. Financial Analyst Journal 31, 3672.

Boguth, O., Simutin, M., 2018. Leverage constraints and asset prices: Insights from mutual fund risk taking. Journal of Financial Economics 127, 325-341.

Brunnermeier, M., Pedersen, L.H., 2009. Market liquidity and funding liquidity. Review of Financial Studies 22, 2201-2238.

D'Avolio, G., 2002. The market for borrowing stock. Journal of Financial Economics 66, 271306.

Easley, D., Engle, R., OHara, M., Wu, L., 2008. Time-Varying Arrival Rates of Informed and Uninformed Trades. Journal of Financial Econometrics 6, 171207.

Easley, D., O'Hara, M., 1987. Price, trade size, and information in securities markets. Journal of Financial Economics 19, 69-90.

Easley, D., OHara, M., Srinivas, P. S., 1998. Option volume and stock prices: Evidence on where informed traders trade. Journal of Finance 53, 431465.

Fama, E.F., MacBeth, J.D., 1973. Risk, return, and equilibrium: empirical tests. Journal of Political Economy 81, 607636.

Fostel A., and Geanakoplos J., 2008. Leverage Cycles and the Anxious Economy. American Economic Review 98, 1211-44.

Frazzini, A., Pedersen, L. H., 2014. Betting against beta. Journal of Financial Economics 111, 1-25.

Garleanu, N., Pedersen, L. H., 2011. Margin based asset pricing and deviations from the law of one price. Review of Financial Studies 24, 19802022.

Garleanu, N., Pedersen, L. H., Poteshman, A. M., 2009. Demand-based option pricing. Review of Financial Studies 22, 4259-4299.

Ge, L., Lin, T., Pearson, N., 2016. Why does the option to stock volume ratio predict stock returns? Journal of Financial Economics 120, 601-622.

Glosten, L.R., Milgrom, P.R., 1985. Bid, ask and transaction prices in a specialist market with heterogeneously informed traders. Journal of Financial Economics 14, 71-100.

Gromb, D., Vayanos, D., 2002. Equilibrium and Welfare in Markets with Financially Constrained Arbitrageurs. Journal of Financial Economics 66, 361-407.

Gromb, D., Vayanos, D., 2018. The Dynamics of Financially Constrained Arbitrage. Journal of Finance 73, 1713-1750.

Goncalves-Pinto, L., Grundy, B.D., Hameed, A., van der Heijden, T. and Zhu, Y., 2020. Why do option prices predict stock returns? The role of price pressure in the stock market. Management Science, forthcoming.

Gould, J. P., Galai, D., 1974. Transactions costs and the relationship between put and call prices. Journal of Financial Economics 1, 105-129.

Goyenko, R., Ornthanalai, C. and Tang, S., 2015. Options illiquidity: Determinants and implications for stock returns. Working Paper, Rotman School of Management.

Grundy, B., Lim, B., Verwijmeren, P., 2012. Do option markets undo restrictions on short sales? Evidence from the 2008 short-sale ban. Journal of Financial Economics 106, 331-348.

Hu, J., 2014. Does option trading convey stock price information?. Journal of Financial Economics 111, 625645.

Hu, J., 2018. Option listing and information asymmetry. Review of Finance 22, 1153-1194.

Hu, J., Kirilova, A., Park, G., Ryu, D., 2020. Who profits from trading options? Working paper, Singapore Management University.

Hu, X., Pan, J., Wang, J., 2013. Noise as information for illiquidity. Journal of Finance 68, 2341-2382.

Jiang, W., 2018. Leveraged Speculators and Asset Prices. Working Paper, Chinese University of Hong Kong.

Kalay, A., Karakas, O., Pant, S., 2014. The market value of corporate votes: Theory and evidence from option prices. Journal of Finance 69, 12351271.

Kamara, A., Miller, T.W., 1995. Daily and intradaily tests of European put-call parity. Journal of Financial and Quantitative Analysis 30, 519-539.

Klemkosky, R., Resnick, B., 1979. Put-call parity and market efficiency. Journal of Finance 34, 1141-1155.

Klemkosky, R., Resnick, B., 1980. An ex ante analysis of put-call parity. Journal of Financial Economics 8, 363-378.

Lamont, O., Thaler, R., 2003. Can the Market Add and Subtract? Mispricing in Tech Stock Carve-outs. Journal of Political Economy 111, 227-268.

Merton, R. C., 1973. The Relationship Between Put and Call Option Prices: Comment. Journal of Finance 28, 183-184.

Mitchell, M., and Pulvino, T., 2012. Arbitrage crashes and the speed of capital. Journal of Financial Economics 104, 469-490.

Muravyev, D., Pearson, N. D., Broussard, J. P., 2013. Is there price discovery in equity options? Journal of Financial Economics 107(2), 259283.

Muravyev, D., Pearson, N. D., Pollet, J., 2018. Understanding Returns to Short Selling Using Option-Implied Stock Borrowing Fees. Working paper, Michigan State University.

Muravyev, D., Pearson, N. D., 2020. Options Trading Costs Are Lower than You Think, Review of Financial Studies, forthcoming.

Newey, W.K., West, K.D., 1987. A simple, positive semi-definite, heteroskedasticity, and autocorrelation consistent covariance matrix. Econometrica 55, 703708.

Odean, T., 1998. Are Investors Reluctant to Realize their Losses? Journal of Finance 53, 1775-1798.

Ofek, E., Richardson, M., Whitelaw, R., 2004. Limited arbitrage and short sale constraints: Evidence from the options market. Journal of Financial Economics 74, 305342.

Pan, J., Poteshman, A., 2006. The Information in Option Volume for Future Stock Prices. Review of Financial Studies 19, 871-908.

Phillips, S.M., Smith, C.W., 1980. Trading costs for listed options the implications for market efficiency. Journal of Financial Economics 8, 179-201.

Ross, S. A., 1976. The arbitrage theory of capital asset pricing. Journal of Economic Theory 13, 341360.

Rytchkov, O., 2014. Asset pricing with dynamic margin constraints. Journal of Finance 69, 405-452.

Stoll, H., 1969. The relationship between call and put option prices. Journal of Finance 24, 801-824.

[Dataset] Center for Research in Security Prices, Daily Close Stock Bid and Ask Prices 2007-2012

[Dataset] Option Metrics, Daily Close Stock Bid and Ask Option Prices 2007-2012

[Dataset] Markit, Security Lending Fee, Total Loanable Shares and Outstanding Shares on Loan 2007-2012

[Dataset] Trade Alert, Options Tick Data 2007-2012

[Dataset] New York Stock Exchange, Trade and Quote Data 2007-2012

Table 1
Sample description
This table describes the sample in the study from 2007 to 2012. To be included, a common stock (CRSP code 10 and 11) must have options prices available in Option Metrics and short selling data from Markit with its stock price above \$5. Stock-day observations with non-dividend stock distributions, loanable shares more than number of shares outstanding, negative stock borrowing fees, crossed or locked close bid and ask prices in either the stock or options market are excluded. Reported for each year as well as the full sample are the total number of stock-day observations, number of unique stocks in the year, average daily stock and options trading volumes and options open interest per stock. Stock trading volume is in number of shares. Options trading volume and open interest are counted in option lots with one lot equivalent to one hundred shares of stocks.

Year	N of ob	N of stocks	Stock volume	Option volume	Open interests
2007	346,723	2,351	2,150,539	3,883	99,157
2008	305,790	2,308	3,060,339	4,669	105,045
2009	278,344	2,160	3,115,314	4,676	91,966
2010	326,319	2,247	2,832,596	4,471	92,019
2011	338,198	2,341	2,726,529	5,091	98,037
2012	319,427	2,295	2,472,760	5,366	96,468
Total	1,914,801	3,330	2,707,798	4,685	97,189

Table 2

Mid quote locations in the two markets

This table compares the synthetic mid quote price with the borrowing-cost adjusted mid quote price in the stock market in the sample described in Table 1. The synthetic bid and ask prices are constructed using a pair of closest-to-the-money call and options as follows:

$$bid_i = (Bid\_Call - EEP\_Call) - (Ask\_Put - EEP\_Put) + PV(K) + PV(Div),$$
$$ask_i = (Ask\_Call - EEP\_Call) - (Bid\_Put - EEP\_Put) + PV(K) + PV(Div),$$

where $PV(K)$ is the present value of the strike price, EEP is the early exercise premium calculated as the difference between the actual midpoint of the option bid-ask prices and the Black-Scholes (1973) European option price, and Div is the present value of the announced dividends before the options maturity. For each underlying stock, only the closest-to-the-money option pair expiring in 10 to 40 days is chosen to calculate the synthetic stock prices every day. The borrowing-cost adjusted bid and ask prices are:

$$bid_a = bid * (1 - lendingfee * t' * exp(-r * t)),$$
$$ask_a = ask * (1 - utilization * lendingfee * t * exp(-r * t)),$$

where bid and ask are the close bid and ask prices in CRSP, $utilization$ is the percentage of shares on loan relative to the total number of shares available for lending, $lendingfee$ is the net stock borrowing cost in percentage, t is the time to expiration of the synthetic stock, t' is t minus three days assuming short sellers deliver stocks three days after the transaction, and r is the risk-free rate of return. The mid quote prices are the average of bid and ask prices labeled as mid_i for the synthetic stock, mid for the actual stock without security lending costs, and mid_a for the actual stock with security lending costs. Panel A reports the descriptive statistics of the ratio and difference between the two mid quote prices of synthetic and actual stocks. Panel B reports the percentage of observations in each category.

Panel A: Descriptive statistics

Variable	N	Mean	Std	Min	Max
mid_i/mid	1,914,801	99.975	0.473	75.291	153.886
mid_i/mid_a	1,914,801	100.001	0.464	75.321	153.895
mid_i - mid	1,914,801	-0.664	14.455	-886.266	1763.82
mid_i - mid_a	1,914,801	-0.046	14.23	-874.539	1764.22

Panel B: Mid quote comparison

year	N	$mid_i \geq mid$	$mid_i < mid$	$mid_i \geq mid_a$	$mid_i < mid_a$
2007	346,723	44.3	55.7	48.35	51.65
2008	305,790	40.45	59.55	44.09	55.91
2009	278,344	44.85	55.15	46.68	53.32
2010	326,319	46.41	53.59	48.99	51.01
2011	338,198	47	53	49.52	50.48
2012	319,427	45.16	54.84	48.86	51.14
Total	1,914,801	44.75	55.25	47.83	52.17

Table 3

Comparing actual and synthetic bid prices

This table compares the synthetic bid price with the borrowing-cost adjusted bid price in the stock market in the sample described in Table 1. The synthetic bid (bid_i), borrowing-cost adjusted actual bid (bid_a) and unadjusted actual bid (bid) are the same as defined in Table 2. Panel Panel A reports the descriptive statistics of the ratio and difference between the two bid prices. Panel B reports the percentage of observations in each category.

Panel A: Descriptive statistics

Variable	N	Mean	Std	Min	Max
bid_i/bid	1,914,801	98.946	1.32	38.793	153.142
bid_i/bid_a	1,914,801	98.973	1.309	38.797	153.158
bid_i - bid	1,914,801	-26.396	36.756	-3353.7	3765.88
bid_i - bid_a	1,914,801	-25.717	36.531	-3344.07	3770

Panel B: Bid prices comparison

year	N	$bid_i \geq bid$	$bid_i < bid$	$bid_i \geq bid_a$	$bid_i < bid_a$
2007	346,723	1.53	98.47	1.94	98.06
2008	305,790	1.07	98.93	1.39	98.61
2009	278,344	1.12	98.88	1.33	98.67
2010	326,319	1.66	98.34	2.12	97.88
2011	338,198	1.94	98.06	2.30	97.70
2012	319,427	2.70	97.30	3.42	96.58
Total	1,914,801	1.69	98.31	2.10	97.90

Table 4
Comparing actual and synthetic ask prices

This table compares the synthetic ask price with the borrowing-cost adjusted ask price in the stock market in the sample described in Table 1. The synthetic ask (ask_i), borrowing-cost adjusted actual ask (ask_a) and unadjusted actual ask (ask) are the same as defined in Table 2. Panel A reports the descriptive statistics of the ratio and difference between the two ask prices. Panel B reports the percentage of observations in each category.

Panel A: Descriptive statistics

Variable	N	Mean	Std	Min	Max
ask_i/ask	1,914,801	101.003	1.284	76.677	161.473
ask_i/ask_a	1,914,801	101.023	1.287	76.688	161.477
ask_i - ask	1,914,801	25.068	36.68	-1934.12	3492.82
ask_i - ask_a	1,914,801	25.53	36.654	-1934.03	3492.82

Panel B: Ask prices comparison

year	N	$ask_i \geq ask$	$ask_i < ask$	$ask_i \geq ask_a$	$ask_i < ask_a$
2007	346,723	97.45	2.55	97.79	2.21
2008	305,790	97.39	2.61	97.95	2.05
2009	278,344	97.72	2.28	98.23	1.77
2010	326,319	97.13	2.87	97.63	2.37
2011	338,198	96.98	3.02	97.54	2.46
2012	319,427	95.96	4.04	96.94	3.06
Total	1,914,801	97.09	2.91	97.67	2.33

Table 5

Locations of actual and synthetic quotes and arbitrage opportunities

This table reports the percentage of stock-day observations for six types of quote locations as described in Figure 1 for individual years as well as the full sample. Synthetic ask (ask_i) and bid (bid_i) are calculated as in Tables 2. Actual ask and bid prices are adjusted for security lending costs in Panel A and unadjusted in Panel B. Type A is when the synthetic ask is above the actual ask and the synthetic bid is below the actual bid. Type B is when the synthetic ask is above the actual ask and the synthetic bid is above the actual bid but below the actual ask. Type C is when the synthetic ask is below the actual ask but above the actual bid and the synthetic bid is below the actual bid. Type D is when the synthetic ask is below the actual ask and the synthetic bid is above the actual bid. Type E is an arbitrage opportunity when both the synthetic ask and bid are above the actual ask. Type F is an arbitrage opportunity when both the synthetic ask and bid are below the actual bid.

Panel A: With lending fees

year	Type A	Type B	Type C	Type D	Type E	Type F
2007	96.16	1.30	1.59	0.30	0.34	0.31
2008	96.73	0.95	1.51	0.17	0.27	0.37
2009	97.00	0.77	1.17	0.10	0.46	0.51
2010	95.52	1.17	1.38	0.01	0.94	0.98
2011	95.25	1.03	1.23	0.02	1.26	1.22
2012	93.51	1.42	1.58	0.01	2.00	1.48
Total	95.66	1.12	1.41	0.10	0.89	0.82

Panel B: Without lending fees

year	Type A	Type B	Type C	Type D	Type E	Type F
2007	96.22	0.99	1.75	0.29	0.24	0.51
2008	96.48	0.71	1.71	0.16	0.20	0.74
2009	96.69	0.66	1.31	0.09	0.37	0.88
2010	95.48	0.85	1.47	0.01	0.80	1.39
2011	95.05	0.82	1.26	0.01	1.11	1.76
2012	93.26	0.98	1.67	0.00	1.72	2.36
Total	95.50	0.84	1.53	0.09	0.75	1.28

Table 6

Transition matrix for different quote types

This table reports the estimated Markov chain transition matrix for the six types of synthetic and actual quote locations as described in Figure 1 in the full sample of 2007 to 2012. Synthetic ask (ask_i) and bid (bid_i) are calculated as in Tables 2. Actual ask and bid prices are adjusted for security lending costs. Type A is when the synthetic ask is above the actual ask and the synthetic bid is below the actual bid. Type B is when the synthetic ask is above the actual ask and the synthetic bid is above the actual bid but below the actual ask. Type C is when the synthetic ask is below the actual ask but above the actual bid and the synthetic bid is below the actual bid. Type D is when the synthetic ask is below the actual ask and the synthetic bid is above the actual bid. Type E is an arbitrage opportunity when both the synthetic ask and bid are above the actual ask. Type F is an arbitrage opportunity when both the synthetic ask and bid are below the actual bid. The transition probabilities are estimated from day $t-1$ to t.

t-1/t	Type A	Type B	Type C	Type D	Type E	Type F
Type A	97.22	0.80	1.04	0.08	0.39	0.47
Type B	68.52	11.56	7.68	0.59	6.85	4.79
Type C	70.49	6.14	12.23	0.50	3.56	7.08
Type D	79.18	5.33	8.51	3.79	1.03	2.15
Type E	41.11	8.93	5.62	0.15	37.98	6.21
Type F	54.73	6.34	12.50	0.30	6.57	19.56

Table 7
Arbitrage profits

This table reports the number of arbitrage opportunities and average arbitrage profit per share for Type E (when the synthetic bid is above the actual ask) in Panel A and for Type F (when the synthetic ask is below the actual bid) in Panel B for individual years as well as the full sample. The synthetic bid (bid_i) and ask (ask_i) prices and the borrowing-cost adjusted bid (bid_a) and ask (ask_a) prices for arbitragers are calculated as in Tables 2. Columns (3) and (4) considers the commission the arbitrager pays to trade 10 lots of stocks and synthetic stocks. Columns (5) and (6) considers the commission the arbitrager pays to trade 1 lot only.

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Type E arbitrage						
			Fee for 10 lots		*Fee for 1 lot*	
year	N	mean	N	mean	N	mean
2007	1,175	0.800	706	1.279	390	2.017
2008	840	0.267	452	0.440	160	0.859
2009	1,294	0.355	636	0.665	291	1.123
2010	3,062	0.311	1,188	0.740	479	1.483
2011	4,252	0.094	1,577	0.186	317	0.384
2012	6,384	0.330	2,898	0.667	1,147	1.332
Total	17,007	0.299	7,457	0.621	2,784	1.297
Panel B: Type F arbitrage						
			Fee for 10 lots		*Fee for 1 lot*	
year	N	mean	N	mean	N	mean
2007	1,070	0.123	557	0.180	113	0.331
2008	1,126	0.087	459	0.150	72	0.330
2009	1,408	0.043	298	0.112	32	0.318
2010	3,208	0.030	511	0.081	42	0.224
2011	4,138	0.040	926	0.089	74	0.326
2012	4,727	0.045	818	0.157	100	0.733
Total	15,677	0.049	3,569	0.128	433	0.411

Table 8

Determinants of the relative ask price

This table examines determinants of the relative ask price in the cross-section. The synthetic ask (ask_i) and borrowing-cost adjusted ask (ask_a) are the same as in Table 2. Reported are the coefficient estimates from daily Fama-MacBeth (1973) regressions of the relative ask defined as $PD\_ask = ask_i/ask_a - 1$ with t-statistics calculated using Newey-West (1980) standard errors. *Spread* is the percentage bid-ask spread of the underlying stock. *Volatility* is the standard deviation of daily stock returns in the past 21 trading days. *Vol_ivol* is the standard deviation of the average implied volatility of the at-the-money call and put option pair with 30 days to maturity using the past 21 trading days. *Ownership* is the institutional holding at the end of the previous quarter. *OOI* and *SOI* are the option delta imbalance and net stock order imbalance calculated as in Hu (2014). All variables are calculated on the same day except *Ownership*. All coefficients are multiplied by 100. ***,**, and * indicate statistical significance at the 1, 5, and 10% level, respectively.

variable	(1)	(2)	(3)	(4)
Intercept	0.251***	1.199***	1.130***	0.337***
	(17.82)	(57.74)	(50.74)	(20.14)
Spread	4.465***			4.228***
	(22.69)			(22.80)
Volatility	0.206***			0.536***
	(5.67)			(18.16)
Vol_ivol	8.127***			8.473***
	(31.81)			(33.79)
Ownership		-0.299***		-0.121***
		(-63.18)		(-20.93)
$\lvert OOI \rvert$			-0.610***	-0.970***
			(-13.86)	(-27.69)
$\lvert SOI \rvert$			-0.006***	-0.010***
			(-16.93)	(-26.75)
Adj. Rsq	0.188	0.01	0.015	0.22
N per day	1305	1312	1312	1305

Table 9

Determinants of the relative bid price

This table examines determinants of the relative bid in the cross-section. The synthetic bid (bid_i) and borrowing-cost adjusted bid (bid_a) are the same as in Table 2. Reported are the coefficient estimates from daily Fama-MacBeth (1973) regressions of the relative bid defined as $PD\_bid = bid_i/bid_a - 1$ with t-statistics calculated using Newey-West (1980) standard errors. *Spread* is the percentage bid-ask spread of the underlying stock. *Volatility* is the standard deviation of daily stock returns in the past 21 trading days. *Vol_ivol* is the standard deviation of the average implied volatility of the at-the-money call and put option pair with 30 days to maturity using the past 21 trading days. *Ownership* is the institutional holding at the end of the previous quarter. *OOI* and *SOI* are the option delta imbalance and net stock order imbalance calculated as in Hu (2014). All variables are calculated on the same day except *Ownership*. All coefficients are multiplied by 100. ***,**, and * indicate statistical significance at the 1, 5, and 10% level, respectively.

variable	(1)	(2)	(3)	(4)
Intercept	-0.261***	-1.192***	-1.139***	-0.338***
	(-19.48)	(-51.29)	(-47.75)	(-21.16)
Spread	-4.363***			-4.121***
	(-23.16)			(-23.34)
Volatility	-0.151***			-0.504***
	(-3.74)			(-15.76)
Vol_ivol	-8.324***			-8.699***
	(-31.19)			(-33.21)
Ownership		0.282***		0.107***
		(53.71)		(16.29)
$\lvert OOI \rvert$			0.673***	1.028***
			(16.78)	(31.78)
$\lvert SOI \rvert$			0.006***	0.011***
			(18.05)	(27.81)
Adj. Rsq	0.183	0.009	0.017	0.216
N per day	1305	1312	1312	1305

Figure 1

Types of actual and synthetic quote locations

This figure shows the six types of actual and synthetic quote locations. The synthetic bid and ask prices are constructed using a pair of closest-to-the-money call and options as follows:

$$bid_i = (Bid\_Call - EEP\_Call) - (Ask\_Put - EEP\_Put) + PV(K) + PV(Div),$$
$$ask_i = (Ask\_Call - EEP\_Call) - (Bid\_Put - EEP\_Put) + PV(K) + PV(Div),$$

where $PV(K)$ is the present value of the strike price, EEP is the early exercise premium calculated as the difference between the actual midpoint of the option bid-ask prices and the Black-Scholes (1973) European option price, and Div is the present value of the announced dividends before the options maturity. For each underlying stock, only the closest-to-the-money option pair expiring in 10 to 40 days is chosen to calculate the synthetic stock prices every day. The borrowing-cost adjusted bid and ask prices are:

$$bid_a = bid * (1 - lendingfee * t' * exp(-r * t)),$$
$$ask_a = ask * (1 - utilization * lendingfee * t * exp(-r * t)),$$

where *bid* and *ask* are the close bid and ask prices in CRSP, $utilization$ is the percentage of shares on loan relative to the total number of shares available for lending, $lendingfee$ is the net stock borrowing cost in percentage, t is the time to expiration of the synthetic stock, t' is t minus three days assuming short sellers deliver stocks three days after the transaction, and r is the risk-free rate of return.