Predatory or Sunshine Trading?

Evidence from Crude Oil ETF Rolls*

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Abstract

We study prices, liquidity, and individual account trading activity around large and predictable ETF “roll” trades in crude oil futures markets. We find narrower bid-ask spreads, greater order book depth, and more trading accounts providing liquidity on roll dates. We estimate that the largest ETF tracking crude oil prices effectively pays round-trip trading costs that average 25 basis points. Overall, the evidence indicates that traders effectively provide liquidity rather than follow predatory strategies in this “resilient” market, as implied by sunshine trading theories and by our modified theory of strategic trading around a predictable liquidation.

I. Introduction

A trader who gains knowledge that another investor will transact a substantial quantity of a security can potentially profit by trading in the same direction as the investor, before subsequently reversing the position. In the case of brokers who are aware of pending client orders, the practice is known as "front running." More broadly, the practice has been dubbed "predatory trading" by Brunnermeier and Pedersen (2005). Their model shows that the practice is disruptive, in that it causes prices to temporarily overshoot the longer-term equilibrium, and causes the investor to realize a less advantageous price.

Admati and Pfleiderer (1991) present an alternative theory of trading around a large predictable order. In their "sunshine trading" theory, investors who intend to make a large transaction publicly announce their intention to trade, thereby attracting additional liquidity suppliers as well as natural counterparties to the market, resulting in smaller price effects and a more advantageous price.

In this paper, we assess the relevance of the competing theories of predatory and sunshine trading by studying individual account trading, overall liquidity levels, and price patterns around the time of large and predictable monthly trades undertaken by a major crude oil Exchange-Traded-Fund (ETF). Rather than holding crude oil inventories, which would entail substantial storage costs, crude oil ETFs often choose to gain exposure to crude oil prices by holding positions in New York Mercantile Exchange (NYMEX) crude oil futures contracts. Since individual NYMEX contracts periodically expire, the strategy involves regularly "rolling" positions by selling the expiring contract and purchasing contracts with more distant expiration dates. Since data on crude oil ETFs Assets-Under-Management is publicly available, the magnitude and direction of ETF roll trading is highly predictable.

We focus in particular on the United States Oil Fund (USO), which is the largest of the ETFs that are designed to provide returns that track crude oil prices.[1] Launched in April 2006, USO's assets-under-management grew rapidly. At its peak in early 2009, USO had more than $4.2 billion under management, equating at prevailing prices to over 90 million barrels of crude oil. Returns to USO investors have lagged crude oil prices, as displayed on Figure 1. On April 10, 2006, when USO initiated trading, the

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[1] Data on USO's assets-under-management are obtained from ALPS Fund Services.

settlement price of the nearest delivery crude oil futures contract was \$68.74, while USO's share price was \$68.02. By the end of 2013, the price of the near delivery crude oil contract had risen to \$98.42, a cumulative increase of 43.2%, while the USO share price had fallen to \$35.32, a cumulative loss of 48.1%.

Some observers have suggested that predatory trading explains the USO share price record. For example, the Wall Street Journal reported that "Since the fund (USO) is so big, it is unable to switch in and out of contracts….without moving markets and giving speculators an opportunity to make bets on those moves."[2] The article quotes a trader as stating that "It's like taking candy from a baby" and asserts that the "... candy comes out of returns of the investors in the fund." Similarly, according to Bloomberg "Professional futures traders exploit the ETFs' monthly rolls to make easy profits at the little guy's expense. Unlike ETF managers, the professionals don't trade at set times. They can buy the next month ahead of the big programmed rolls to drive up the price."[3]

We study trading activity and market prices around the time of the USO rolls to assess whether predatory trading of type predicted by Brunnermeier and Pedersen (2005) occurs and affects USO's share price performance. The Brunnermeier and Pedersen model focuses on large pending orders that are predictable to potential predators. USO's roll orders are large, at times exceeding ten percent of typical NYMEX daily volume, and are fully predictable. At the same time, commodity ETFs, being designed to provide passive exposure to commodity price changes, are unlikely to be perceived as informed. Preannounced trades by credibly uninformed traders comprise sunshine trading as envisioned by Admati and Pfleiderer (1991). USO's stated investment objective involves tracking futures settlement prices, which are established during a short two-minute interval at the end of the normal trading day.[4] Since

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[2] "U.S. Oil Fund Finds Itself at the Mercy of Traders", by Gregory Meyer and Carolyn Cui, The Wall Street Journal, March 6, 2009, page C1.

[3] "ETFs Imperil Investors as Contango, Pre-Roll Conspire", by Peter Robison, Asjylyn Loder and Alan Bjerga. Bloomberg Newsroom, July 22, 2010. The article goes on to quote a trader as saying "I make a living off the dumb money.....These index funds get eaten alive by people like me."

[4] USO's investment objective is stated on the company website http://www.unitedstatesoilfund.com/ as follows: "The investment objective of USO is for the daily changes in percentage terms of its units' net asset value ("NAV") to reflect the daily changes in percentage terms of the spot price of light, sweet crude oil delivered to Cushing, Oklahoma, as measured by the changes in the price of the futures contract for light, sweet crude oil traded on the New York Mercantile Exchange (the "NYMEX") that is the near month contract to expire, except when the near

crude oil ETFs predictably demand a very large quantity of liquidity during a short trading interval, their trades provide a powerful opportunity to assess the empirical relevance of the predatory and sunshine trading theories.

We employ data on individual orders and trades in crude oil futures made available to us by the Chicago Mercantile Exchange, which owns and operates the NYMEX market. In addition, we use Commodity Futures Trading Commission (CFTC) data that identifies the individual trading accounts associated with each crude oil futures transaction. The former dataset allows us to study posted liquidity in the form of bid and ask quotes, as well as unexecuted displayed depth in the limit order book. The latter dataset allows us to evaluate the strategies used by owners of specific trading accounts around the time of USO's rolls. Our study of individual orders and trades spans the period March 1, 2008 to February 28, 2009, and therefore includes twelve monthly rolls. We also study daily crude oil settlement price data for the longer time interval January 1990 through December 2013.

In addition to providing empirical evidence, we provide some new analysis of the economics of strategic trading around a known liquidation. Brunnermeier and Pedersen (2005) rely on a model where trades have permanent effects on price, and show that the effects of predatory trading are worst when there is a monopolist predator. We analyze the effects of strategic trading when markets are resilient, in the sense that some or all of the immediate price impact of trades is subsequently reversed. Our analysis reveals that, when the market is reasonably resilient, the profit maximizing strategy for a monopolist strategic trader who is aware of a pending liquidation is to sell before (and, for some parameters, after) the period where the liquidator sells, while purchasing during the period that the liquidator sells. In other words, the strategic trader essentially chooses to absorb a portion of the liquidator's order imbalance while it occurs, while offloading the resulting inventory both before and after the liquidation. The effect of the strategic trades is to increase rather than decrease the liquidator's proceeds. Our analysis shows that the key implication of the Brunnermeier and Pedersen (2005) model, that a profit-maximizing

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month contract is within two weeks of expiration, in which case it will be measured by the futures contract that is the next month contract to expire (the "Benchmark Oil Futures Contract"), less USO's expenses."

strategic trader will necessarily degrade market quality and reduce liquidator proceeds, do not generalize to a resilient market.

Our empirical analysis reveals several findings. First, the oil futures market is indeed resilient. Using CME order book data, we estimate (a) the permanent and temporary component of trading costs and (b) a resiliency parameter that captures the extent to which temporary price impacts persist beyond the period of the order imbalance. The resulting estimates imply that over 99% of the temporary price impact due to an order imbalance in the expiring contract is reversed within ten minutes. For the second nearest-to-expiration contract, over 95% of the temporary price impact is reversed within 15 minutes, which is still highly resilient in the context of our strategic trading model. We also document a reduction in the permanent price impact of order imbalances on ETF roll days.

Second, we find that several measures indicate improved liquidity on roll versus non-roll days. In particular, quoted and effective bid-ask spreads are narrower on roll days, and the quantity of unexecuted orders in the limit order book at prices near the inside is greater on roll days. Further, a larger number of distinct accounts provide liquidity through limit orders on ETF roll days relative to non-roll days. These findings are consistent with Admati and Pfleiderer's (1988, 1991) prediction that preannouncement by a large liquidity trader increases market size by attracting liquidity providers and natural counterparties.[5]

Third, based on the CFTC data, we find little or no evidence that individual trading accounts use strategies that would reasonably be considered predatory, in the sense of the Brunnermeier and Pedersen (2005) model. In fact, consistent with the simple framework introduced in our paper, we find significant increased usage of a liquidity provision strategy where strategic traders sell the expiring contract the trading day before the roll and offload the resulting position on and after the roll day, thereby absorbing a portion of the ETF sales during the roll day, while shifting a portion of the selling pressure to the preceding day. Our theoretical analysis implies that this strategy mitigates temporary price impacts and improves prices for the rolling ETF.

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[5] In the limit order book model of Foucault, Kadan, and Kandel (2005), an increase in the proportion of liquidity suppliers narrows the bid ask spread as liquidity suppliers compete by submitting more aggressively priced limit orders. The preannouncement strategy can be viewed as an event that increases the proportion of liquidity suppliers.

Fourth, our analysis of daily settlement prices indicates that USO does pay to execute its roll trades – about 25 basis points on average per roll, or 3% per year, in the form of adverse changes in settlement prices at the time of the rolls. While this estimate indicates a substantial roll cost associated with the ETFs large liquidity demand, it is not excessive relative to the estimated costs of executing large trades in other markets, including large-capitalization equities. Finally, we discuss the relevance of the term structure of crude oil prices and reconcile the lack of evidence in support of predatory strategies with the apparent investment underperformance documented in Figure 1.

The findings of our study are relevant for portfolio managers who need to rebalance their portfolios for non-informational reasons. For example, revisions to the set of stocks comprising a stock index are typically disclosed in advance of the index reconstitution date, while participants who seek to track the index return must trade on the reconstitution date. The prior literature has shown that index reconstitution is associated with higher trading activity and significant abnormal returns prior to the event, including both transitory price pressure and the permanent effects of index membership (see Madhavan (2003) and Chen, Noronha and Singal (2004)). Some index funds and transition portfolio managers choose to not disclose the exact timing of their trades, partly in anticipation of predatory trading strategies.[6] Our study shows that predatory trading is unlikely to degrade market quality in the absence of long lived price impacts, implying that the preannouncement of trading intentions is a viable strategy for large non-informed traders in more resilient markets.[7]

The rest of the paper is organized as follows. Section II discusses the related literature, the NYMEX market structure, data sources and summary statistics on USO trading activity on roll days. Section III describes the change in market quality surrounding the roll days. Section IV presents a model of trading by a monopolist predator and Section V estimates the resiliency of the NYMEX crude oil market. Section

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[6] For example, Vanguard Emerging Markets Stock Index Fund and ETF recently adopted the FTSE Emerging Index as the new target index for the fund, replacing the MSCI Emerging Markets Index. In describing the adjustments to fund investors, Vanguard states that "To protect the fund from the potential for harmful front-running by traders, the exact timing of the index changes will not be disclosed in advance to investors."

[7] In contrast, our analysis confirms that predatory trading can harm liquidators and market quality when trades contain information that permanently alters prices, or when markets are not resilient. Privately informed traders whose orders can permanently alter prices should indeed be concerned about predatory or "order anticipation" strategies.

VI examines account level activity by strategic traders surrounding the roll while Section VII assesses the relevance importance of the futures term structure and trading costs for the performance of USO' stock price.

II. Related Work, Data Sources, and NYMEX market structure

a. Related Literature

A number of studies quantify aspects of risk and return in commodity futures markets.[8] Separately, a large literature has assessed trading strategies and the costs of completing trades, primarily focusing on traditional investment markets such as stocks and bonds. Our study contributes in part by assessing trading costs for large traders in an important commodity market.[9] However, our central contributions come in assessing the implications of the theories of predatory trading and sunshine trading, in a setting where both theories potentially apply.

Brunnermeier and Pedersen (2005) model the case where some traders become aware of another trader's need to liquidate a position, and introduce the label "predatory trading" to describe the strategies followed. In their model the predators sell alongside the liquidating trader, before reversing their positions. Their trades damage market quality in that they cause the price to temporarily overshoot its long-term equilibrium. Further, their profits come at the expense of lower proceeds to the liquidating trader. Carlin, Lobo, and Vishwanathan (2007) present a multi-period model in which traders typically provide liquidity to each other. However, in situations where the potential profit from following a predatory strategy is sufficiently large, traders can abandon liquidity provision to follow predatory strategies.[10] Their model therefore predicts episodic periods of illiquidity due to predation.

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[8] Recent examples include Hong and Yogo (2012), Gorton, Hayashi, and Rouwenhorst (2008), and Erb and Harvey (2006).

[9] See, for example, Keim and Madhavan (1997) and Jones and Lipson (2001) for evidence from equity markets, Schultz (2001) and Bessembinder, Maxwell and Venkataraman (2006) for evidence from corporate bonds, and Manaster and Mann (1996) for evidence on financial and agricultural commodities, and the papers referenced there.

[10] John Meriwether, who managed Long Term Capital Management (LTCM), attributes the collapse of the hedge fund to predatory trading strategies "The few things that we had on that the market didn't know about came back quickly. It's the trades that the market knew we had on that caused us trouble." (see Lewis (1999)).

The model presented by Brunnermeier and Pedersen (2005) assumes that trades have strictly permanent price impacts proportional to the size of the order imbalance. However, numerous studies have documented that large financial market trades can have both temporary and permanent price impacts. Schoneborn and Schied (2007) show that strategic traders may react to known liquidations by trading in the opposite rather than the same direction as the liquidator when price impacts are temporary. Our model extends theirs in that we also assess the effect of market "resiliency," i.e. the extent to which trades' temporary price impacts spill over to periods subsequent to trade execution. This extension is important in our setting, because although ETF roll trades are unlikely to have permanent price impact, long-lived temporary price impacts could accommodate predatory trading.

Admati and Pfleiderer (1991) consider a trader who needs to complete a large transaction and who is not motivated by private information regarding asset value. They show that a public announcement of the intent to trade, termed "sunshine trading," can attract liquidity suppliers who might not otherwise have been present, and can therefore allow the trader to achieve a more favorable price.

Our empirical analysis of potential price impacts of roll trades in commodity futures is not entirely unprecedented. Stoll and Whaley (2010), Mou (2011), and Aulerich, Irwin, and Garcia (2012) study commodity trading by index investors. In contrast to specialized ETFs that focus on a single commodity, index investors seek to generate returns that match the performance of multi-commodity indices, such as the Standard and Poor's-Goldman Sachs Commodity Index (SP-GSCI). To the extent that these index investors rely on futures positions to track the indices, they also generate periodic roll trades.[11] Mou (2011) reports that significant profits can be earned by investors who trade in advance of the dates that the SP-GSCI index begins to track the second-rather than nearest-to-expiration futures contract. In contrast, Stoll and Whaley (2010) find little or no price effects around index shift dates in a broad cross-section of commodity futures prices. Also, in work contemporaneous to our own, Aulerich, Irwin, and Garcia (2012) use CFTC data regarding changes in actual positions held by index traders, and report a narrowing

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[11] In addition, a number of authors have assessed whether index investors and other passive long-only investors have affected the level and/or the volatility of commodity prices. See, for example, Brunetti and Buyuksahin (2009), Buyuksahin and Harris (2011), Irwin and Sanders (2012), and Kilian (2009).

rather than a widening of price spreads between the second nearest to maturity and the nearest to maturity contracts when investors roll their positions, in an array of agricultural contracts.

Our study is distinguished from these in that we are able to exploit data on individual trades, with account identifiers, as well as individual limit order book updates to assess the relevance of sunshine and predatory trading theories. In addition, we present a model of strategic trading around a known liquidation that extends prior work, estimate trade execution costs and market resiliency for an important commodity market, and explain the apparent underperformance of the largest crude oil ETF.

b. The NYMEX Market

The New York Mercantile Exchange trades crude oil and other energy futures contracts. NYMEX prices are widely-used benchmarks for valuing derivative contracts and determining final prices for over-the-counter contracts. Although the NYMEX continues to operate a physical trading floor, the large majority of transactions occur on the NYMEX's electronic limit order market, known as Globex. In addition, large traders can negotiate block trades. Though physical delivery is rare, each individual NYMEX crude oil contract calls for delivery of 1,000 barrels of crude oil at Cushing, Oklahoma, during a designated delivery month. Transaction prices reflect prices at which oil is to be delivered in the future, not an amount paid to enter the contract. Trading hours for floor trades are 9:00 AM to 2:30 PM New York time. Globex trading occurs around the clock, except for a 45 minute break from 4:15 PM to 5:00 PM New York time. The weighted average price during the two-minute interval 2:28 to 2:30 PM comprises the contract's "settlement price" for the day, and is used to calculate gains and losses on outstanding positions. In particular, long positions receive and short positions pay the change in the settlement price since the prior day (or since the transaction price if entered the same day). In addition to outright trades that specify a delivery price, the NYMEX offers "Trade-at-Settlement" (TAS) contracts. The futures price for a TAS trade is the current day settlement price (potentially plus or minus a specified margin), and is generally not known at the transaction time.

c. Data Sources

We employ four main datasets. The Commodity Futures Trading Commission (CFTC) provided data on all completed trades in NYMEX crude oil futures from March 1, 2008 to February 28, 2009. The CFTC data includes floor and block trades, as well as trades completed on the Globex electronic market. In addition to trade type, contract, price, and volume, the CFTC data includes an account identification variable for each trade. The account identifiers allow us to assess the number of unique trading accounts active on a given day and to track inventory changes by account. Although the buy and sell account is identified for each trade, the initiator of the trade is not. We use a modified Lee-Ready algorithm to assign trades as buyer- or seller-initiated.[12]

We also obtain for the same time period from the Chicago Mercantile Exchange (owner of the NYMEX) a 5-level deep representation of the limit order book and a record of completed trades for crude oil futures on the electronic GLOBEX market. The CME dataset allows us to construct a continuous record of best bid and ask quotes, as well as the depth of unexecuted orders at and behind the best quotes.[13] Third, we obtain from the United States Energy Information Agency (EIA) a daily record of settlement prices for NYMEX crude oil contracts traded over the longer time interval January 1999 through December 2013. Finally, we obtain from ALPS Fund Services a daily record of USO's Total Net Assets Under Management. USO's roll dates are identified based on their publicly stated investment objective, by which the fund tracks the price of the nearest-to-expiration NYMEX contract until two weeks before expiration, after which the fund tracks the second-nearest-to-expiration contract price.[14]

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[12] Specifically, to sign trades, we compare the transaction price with the contemporaneous quote-midpoint (without a 5-second lag), and consider up to five preceding trades to implement the tick-rule.

[13] In addition to the "outright" book for each contract, the CME maintain a limit order book for calendar spread orders. Each leg of the spread order competes for order flow with the corresponding outright book. Further, the CME data has a finer time resolution (to the 100th of a second) as compared to the CFTC data, for which time stamps are truncated to the second. We use the CME transactions to impute centi-second time stamps for CFTC data transactions through an iterative process of matching unique price-quantity pairings. When transactions cannot be perfectly matched between the two datasets, the latest-possible time stamp is imputed within the CFTC dataset to avoid any possible look-ahead bias of matching trades with LOB information. A limitation is that the CME data does not include floor trades or negotiated block trades.

[14] An ETF is required to describe the benchmark that it will seek to track, and its tracking strategy, in documents filed with the listing exchange and the Securities and Exchange Commission (SEC). Some ETFs choose to disclose their daily holdings and the exact schedule of roll dates over the next twelve months on their webpage. Other ETFs more broadly describe their roll schedule and/or the benchmark index that they track in their prospectus.

d. Descriptive Statistics

Our main analysis focuses on the period March 1, 2008 to February 28, 2009, during which we have data on individual crude oil trades. USO's assets-under-management (AUM) grew significantly during this period, from $0.47 billion in March 2008 to $3.92 billion in February 2009. Table 1 reports estimated USO roll activity as a percentage of market volume for each monthly roll date, for the "front" (nearest-to-expiration) crude oil contract and for the second nearest-to-expiration contract. Roll activity is estimated based on USO's assets under management relative to the roll-date settlement price, and shows rapid growth during the sample, with sales of the front contract increasing from 4,445 contracts representing 1% of market volume during the March 2008 roll to 67,882 contracts representing 13.0% of market volume during the February 2009 roll.[15] Aggregated across the twelve roll dates, net roll activity comprised 4.9% of roll-day volume in the front contract. Roll-date purchases accounted for 9.3% of roll-day volume in the more lightly traded second contract.

Table 1 also reports market volume during the two-minute settlement period. Since ETF performance is benchmarked against the changes in settlement price, ETFs generally try to track the settlement price on the roll day. We document that USO's roll volume on average exceeds market volume during the settlement period, indicating that it would be difficult for USO to execute its entire roll by use of regular trades during the settlement interval. Many Crude oil ETFs employ TAS contracts to ensure a price that closely matches the benchmark settlement price. To the extent that a TAS counterparty to an ETF trade has a 'natural' offsetting position, the TAS trade allows both the ETF and counterparty to offset positions at low cost.[16] If the TAS counterparty is simply providing liquidity, then compensation takes the form of the difference between roll-day settlement prices (plus or minus any margin) and the average price of counterparties' offsetting trades.

USO's investment objective, as well as a calendar schedule of recent and future roll dates, are disseminated on the web site http://www.unitedstatesoilfund.com/.

[15] Our estimates of USO's roll date volume may differ slightly from the fund's actual volume if a portion of assets under management have not yet been invested, or if some roll activity takes place in OTC markets.

[16] An example would be an oil producer, who would hedge oil price risk with short positions, and would need to roll forward the short position in expiring contracts. ETF's reliance on TAS contracts has been discussed in popular press articles. See for example, Financial Times article, http://ftalphaville.ft.com/2010/07/15/287061/the-end-of-diversification.

III. Measuring Liquidity on roll and Non-roll Days

Carlin, Lobo, and Viswanathan (2007) present a model of large traders who most often cooperate by providing liquidity to each other. However, they show that in situations where the short term profits are large enough, these traders may abandon liquidity provision to instead engage in predatory trading. In Brunnermeier and Pedersen (2005), predation occurs with any known liquidation. The theories of Admati and Pfleiderer (1988, 1991), in contrast, imply that the preannouncement of trading intentions, can attract natural counterparties and additional liquidity providers. Theoretical models of limit order markets, e.g. Foucault, Kadan and Kandel (2005), predict that an increase in competition among liquidity providers reduces the bid-ask spread and improves market resiliency.

We provide some initial evidence on the relevance of predatory versus sunshine trading theories by simple comparisons of market outcomes across roll and non-roll days in the March 2008 to February 2009 period. The USO roll occurs prior to what might be termed the "market roll" i.e. when overall trading activity and open interest moves from the front month contract to second month contract (see Figure 2). Since the market roll itself can induce changes in market conditions, we compare trading activity during the roll period to a non-roll period that precedes the USO roll date. Specifically, we define the three to seven days prior to the USO roll as the non-roll period.

We compare roll period and non-roll period measures for each minute between 9:00 AM and 3:00 PM EST, and report results averaged across minutes. We address non-normality attributable to potential time-of-day effects by implementing a non-parametric (Wilcoxon signed) test, which requires less stringent distributional assumptions for tests of difference in location.

a. Analysis of the front and second month contracts

Results, reported on Table 2, verify that trading volume per minute (measured based on the CFTC data) is substantially greater on roll days, averaging 777 contracts in the front month and 355 contracts in the second month, compared to 575 contracts in front month and 193 contracts in the second month on non-roll days. Figure 3, Panel A displays average trading volume by minute for roll and non-roll days. Most notable is the spike in trading activity at the time of the daily settlement, particularly on roll days.

We examine several additional measures using the NYMEX order data. The standardized "trade imbalance" measure for each minute is based on the difference between buyer-initiated (a buy market order executes against a standing sell limit order) and seller-initiated (a sell market order executes against a standing buy limit order) volume. To account for intraday patterns, we normalize the measure by subtracting the mean and dividing by the standard deviation of imbalance observed during the same minute on both roll and non-roll periods. In the front contract the net trade imbalance is on average negative on roll days while for the second contract the imbalance is positive on roll days. This trade imbalance is consistent with the use of marketable orders by large traders (USO, or the counterparties to its TAS contracts) to sell the first contract and buy the second contract on roll days.

Importantly, the evidence indicates enhanced liquidity provision on roll days. Quoted bid-ask spreads (the difference between the lowest limit price for unexecuted sell orders and the highest limit price for unexecuted buy orders) on roll days decline from an average of 1.17 basis points to 1.13 basis points in front contract, and from 1.52 basis points to 1.42 basis points in second contract. Figure 3, Panel B displays average quoted spreads by minute for roll and non-roll days. The patterns indicate smaller intraday quoted spreads for the majority of minutes on roll days. These declines, while modest, are statistically significant, and must be evaluated in light of the substantial increase in liquidity demand attributable to the USO rolls, which might have been anticipated to widen spreads.

We also assess liquidity supply by computing the "depth" of unexecuted orders in the limit order book. In particular, we determine the total volume of unexecuted sell (ask depth) and buy (bid depth) orders at prices within four ticks of the most competitive prices. Bid depth for the front contract, which is relevant for those seeking to sell, increases from an average of 47.6 contracts on non-roll days to 51.9 contracts on roll days (t-statistic = 10.98), while ask depth (relevant for those seeking to buy) for second contract increases from an average of 18.5 contracts to 20.5 contracts (t-statistic = 9.07). Figures 4 display average bid and ask depths by minute for roll and non-roll days and support increased liquidity provision in both contracts throughout the day.

Next, we examine effective bid-ask spreads, defined as twice the excess of the trade price over the bid-ask midpoint for each buyer-initiated trade and twice the excess of the midpoint over the trade price for each seller-initiated trade. Effective spreads differ from quoted spreads because large trades can execute outside the quotes, and due to "hidden" orders in the limit order book. We focus on the volume-weighted effective spreads for individual trades for each minute. The results indicate modest reductions in effective spreads, from an average of 2.03 basis points to 1.96 basis points (t-statistic = -3.97) for the front contract, and from 2.42 basis points to 2.29 basis points for the second contract (t-statistic = -3.97).

Finally, we use the CFTC data to assess the number of distinct accounts that supply liquidity on roll and non-roll days. An account is deemed to supply liquidity if more than one buy (sell) limit order posted by the account for the front (second) contract is executed on the corresponding day. We find that an average of 10,470 distinct accounts provide liquidity in the front contract on roll days, compared to 9,698 accounts on non-roll days. For the second contract the number of liquidity-supplying increases from 860 accounts on non-roll days to 1,416 accounts on roll days.

These comparisons of liquidity across roll and non-roll days provide results consistent with the sunshine trading theory of Admati and Pfleiderer (1991), who predict that the announcement of an upcoming trade by a credibly non-informed trader will attract additional liquidity suppliers to market. In particular, despite large liquidity demand on roll days, quoted spreads and effective spreads (which measure costs of trading) decline, while quantities of unexecuted orders on the relevant side of the limit order book and the number of distinct accounts providing liquidity both increase.

b. A discussion of alternative "roll" strategies.

To meet its formal investment objective, USO's roll activity mainly involves sale of the expiring contract and purchase of the second-nearest-to-expiry contract. An alternative would be to roll into contracts with more distant maturity dates. For example, the United States 12 Month Oil Fund (USL) seeks to deliver returns that match the average price change of the nearest- to 12th nearest-to-expiration

NYMEX contracts, which can be accomplished by holding equal positions in each of the crude oil futures contracts from the front month through the 12th nearest-to-expiration contract.[17] This alternative reduces the number of contracts that need to be rolled each month.

In Panel B of Table 2, we report results relevant to the desirability of using long-maturity futures for large ETFs. We note that trading activity decreases rapidly with the maturity of the futures contract. Specifically, trading volume per minute declines from 193 contracts for second month to 78 contracts for third month, and to only 5 contracts for the twelfth month. We also observe a significant decline in book depth, particularly on the Ask side of the book, and a two- to three-fold increase in both quoted spread and effective spread measures for the longer maturity contracts. Since the longer maturity futures contracts are quite illiquid, they are unlikely to represent a viable alternative for large ETFs.[18]

IV. A Model of Trading by a Monopolist Predator

Brunnermeier and Pedersen (2005) present an influential model of predatory trading around the time of a known liquidation. Their model implies that the predator's actions degrade market quality, causing the market price to overshoot its longer-term equilibrium, and reducing liquidator proceeds. In this section, we present a model that, despite some simplifications, extends Brunnermeier and Pedersen. Brunnermeier and Pedersen assume that the price impact of trades is entirely permanent. In contrast, we consider a setting where trades can have both permanent and temporary price impacts, and where the duration of the temporary price impact depends on the "resiliency" of the market. Allowing for temporary price impacts is particularly important when assessing possible predatory trading strategies at the time of predictable orders by non-information-motivated traders.

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[17] http://www.unitedstates12monthoilfund.com/.

[18] In addition, the ETF's benchmark when investing in longer maturity contracts is based on prices of those longer maturity positions, which tend to be less correlated with spot price changes, implying increased basis risk for investors interested in hedging changes in spot crude oil prices. ETFs can also obtain exposure to oil prices using swaps or other derivatives sold by commodity dealers. It is our understanding that some ETFs avoid non-exchange traded instruments because they tend to be sparsely traded in over-the-counter markets and raise regulatory concerns regarding the calculation of Net Asset Value (NAV).

Our main finding is that the implication that predatory trading is necessarily damaging does not generalize to a resilient market. The predator (who we refer to by the more benign label "strategic trader") can instead improve market quality and liquidator proceeds. To make this point in the simplest manner possible we focus on a monopolist trader in the absence of uncertainty. This case is of particular interest, since Brunnermeier and Pedersen show that a single predator is most damaging to the liquidator, while multiple predators compete with each other, mitigating their adverse effects.

a. The Setting

We assume that the investor must liquidate a known quantity, Q_L. A strategic trader is aware of the liquidation, and can trade before, simultaneous with, or after the liquidation, and chooses transaction quantities to maximize profits. Strategic trades sum to zero across periods; that is the strategic trader ultimately does not absorb the liquidator's position. Order imbalances generated by the strategic trader as well as the liquidator are absorbed by the limit order book, the dynamics of which are described in the next section.

b. Trade Prices when the market is resilient.

The model of trade prices presented here is an extension of that presented in Chapter 15 of Hasbrouck (2007). The private information conveyed by trades is measured by a permanent price impact parameter, λ, and the security value evolves according to $V_t = V_0 + \lambda Q_t$, where q_i is signed marketable order flow in period i, and $Q_t = \sum_{i=1}^{t} q_i$ is the accumulated order flow since base period 0.

Trades also have temporary price impacts. The immediate temporary price impact, γq_i, is proportional to the signed order flow, reflecting that small orders execute at quotes that differ from security value and that larger orders walk up the limit order book. The temporary price impact potentially persists, if the limit order book is not refilled instantaneously. Specifically, the trade price at time t depends on current and prior order flow according to:

$$P_t = V_t + \gamma A_t = V_0 + \lambda Q_t + \gamma A_t \tag{1}$$

where $A_t = \sum_{j=0}^{t-1} \theta^j q_{t-j}$.

Let $M_t = V_0 + \lambda Q_{t-1} + \gamma\theta A_{t-1}$ denote the midpoint. Then, we can also state $P_t = M_t + (\lambda+\gamma)q_t$.

Here, A_t is a weighted sum of orders from time 0 to t, and the parameter θ measures the (inverse) resiliency of the market. If θ = 0 the market is completely resilient, and the temporary price impact of the order at time t has no effect beyond time t. This requires that the limit order book refill instantaneously after an order is executed. If so, the midpoint equals the pre-trade value, and $P_t = V_{t-1} + (\lambda+\gamma)q_t$. If $0 < \theta < 1$ the limit order book takes time to refill, the temporary effect of the time t order flow extends beyond time t, and the midpoint differs from underlying value as a function of recent order imbalances. If θ = 1 the temporary impact is never reversed, and thus is indistinguishable from permanent impact.

c. Market Prices and Outcomes

Trading occurs during three intervals: before, during, and after the investor's liquidation. We will interpret each interval as comprising a trading day. Let Q_p, Q_d, and Q_a denote net signed order flow (sum of liquidator and strategic trading) during the "pre", "during", and "after" days, respectively.

For simplicity we consider the case where trading during each day is spread evenly across N periods, in which case $A_t = qY_t$, where $Y_t = \sum_{j=0}^{t-1} \theta^j$. Define also $\overline{Y}_N = \sum_{t=1}^{N} Y_t / N$, which is the average of Y_t across periods 1 to N. Let V_1 denote the value of the security at the beginning of the "pre" day. Given these simplifications, the average trade price across the N periods of the "pre" day can be written as:

$$\overline{P}_p = V_1 + I_0 Q_p, \text{ where } I_0 = \left[\lambda \frac{(N+1)}{2N} + \frac{\overline{Y}_N \gamma}{N} \right]. \tag{2}$$

The average trade price for the "during" day is:

$$\overline{P}_d = V_1 + I_1 Q_p + I_0 Q_d, \text{ where } \quad I_1 = \left[\lambda + \frac{Y_N^2 \gamma\theta}{N^2} \right], \tag{3}$$

and the average trade price for the “after” day is:

$$\overline{P}_a = V_1 + I_2 Q_p + I_1 Q_d ,+ I_0 Q_a , \text{ where } I_2 = \left[\lambda + \frac{Y_N^2 \gamma \theta^{(N+1)}}{N^2} \right]. \tag{4}$$

The parameters I_0, I_1 and I_2 measure the effects on *average* trade prices of same day, prior day and second prior day order imbalances. These depend on market resiliency. When $\theta = 1$ we have $I_1 = I_2 = (\lambda+\gamma)$, and $I_0 = \left[[\gamma + \lambda] \frac{(N+1)}{2N} \right]$. In this case the temporary and permanent price impacts are indistinguishable, and the full price impact $(\lambda+\gamma)$ of the current day order imbalance carries over to subsequent days. The effect of the current day order imbalance on the same day average price is smaller by the factor $(N+1)/2N$, which approaches ½ as the number of periods in the day becomes large.

Price impacts are reduced when $\theta < 1$, and more so the more so the smaller is θ, i.e. the more resilient is the market. In particular, when $\theta = 0$ we have $I_1 = I_2 = \lambda$, and $I_0 = \left[\lambda \frac{(N+1)}{2N} \right] + \frac{\gamma}{N}$.

Let Q_L denote the liquidator sales on the “during” day. We can describe the strategic trader’s order flows by a pair of proportionality parameters ρ_d and ρ_p, defined so that positive values indicate trading in the same direction as the liquidator. Including the requirement that the strategic order trader order flow sums to zero across the three days, the imbalance absorbed by the limit order book (the sum of liquidator and strategic order flow) each day is:

$$Q_p = -\rho_p Q_L , \tag{5}$$

$$Q_d = -(1 + \rho_d) Q_L , \tag{6}$$

and $Q_a = Q_L(\rho_d + \rho_p)$. (7)

Given these assumptions, the liquidator’s proceeds depend on the average price during the liquidation day:

$$LP = Q_L \overline{P}_d . \tag{8}$$

The quantity liquidated is ultimately absorbed by the limit order book. The total acquisition cost paid by limit order traders is:

$$AC = Q_L \rho_p \overline{P}_p + Q_L (1-\rho_d)\overline{P}_d - Q_L(\rho_p + \rho_d)\overline{P}_a \,. \tag{9}$$

The strategic trader's profits can be stated as:

$$SP = Q_L\left[\rho_p(\overline{P}_p - \overline{P}_a) + \rho_d(\overline{P}_d - \overline{P}_a)\right] , \tag{10}$$

which demonstrates that the strategic profits are driven by differences in average trade prices across days. Using expressions (5) to (7) in expressions (2) to (4) for prices, straightforward calculus reveals that strategic trader profits are maximized when:

$$\rho_d^* = \frac{2I_0 - I_1}{4I_1 - 6I_0 - I_2} \tag{11}$$

and

$$\rho_p^* = \frac{-I_1}{2(I_2 - 2I_0)} + \frac{I_1 - 2I_0}{8I_1 - 12I_0 - 2I_2} \,. \tag{12}$$

For comparison to Brunnermeier and Pedersen, we also consider the case where the strategic trader does not transact on the "pre" day. The restricted first order condition is:

$$\rho_d^* = \frac{I_0 - I_1}{2(I_1 - 2I_0)} \,. \tag{11A}$$

d. Illustration of Model Implications

Table 3 illustrates the outcomes of this analysis. The illustration includes an initial price (V_0) equal to \$100, N = 32 fifteen minute periods within each eight-hour trading day, Q_L = 20 units liquidated, temporary price impact, $\gamma = 0.5$, permanent price impact, $\lambda = 0.015$, for values of the (inverse) resiliency parameter, θ, ranging from zero to one. These parameters imply a permanent price impact of 20*.015/100 = 30 basis points from the liquidation. The temporary price impact if the full 20 units were brought to market in a single period would be 20*0.5 = 10%. Of course the liquidation would actually spread over at least the 32 periods of the "during" day.

The column of Table 3 labeled “base” reports outcomes, including both the liquidator’s proceeds (LP, from expression 8) and limit order traders’ acquisition cost (AC, from expression 9) for the 20 units, when the strategic trader is absent. Given these price impact parameters, liquidator proceeds in the absence of strategic trading declines with θ, i.e. as the market is less resilient, from $1990.7 when θ = 0 to $1893.8 when θ = 1. The next set of columns report outcomes when the strategic trader selects quantities to maximize profits, according to expressions (11) and (12), followed by columns that report outcomes when the strategic trader maximizes profits subject to a no-trading-prior constraint (expression 11A). The columns labeled “Pre”, “During”, and “After” report the profit maximizing strategic trader order flow as a proportion of the liquidator sale, with positive values indicating trading in the same direction as the liquidator. The column “SP” reports the strategic traders profit from expression (10).

Despite our use of simplifying assumptions, our results confirm those of Brunnermeier and Pedersen when we assume, as they did, that trades’ price impacts are fully permanent (θ = 1). When constrained to not trade prior to the liquidation, the strategic trader sells simultaneous with the liquidator, and reverses by buying the following day. The profit maximizing quantity transacted by the strategic trader is, given these parameters, 7.75 times the size of the liquidation itself, and the liquidator’s proceeds are reduced dramatically, from $1893 in the absence of strategic trading to $1071 when the strategic trader is present.

The consistency of results with those of Brunnermeier and Pedersen hinge crucially on the permanence of the price impacts. Reducing the θ parameter, i.e. introducing resiliency to the market, rapidly reduces the extent to which the profit-maximizing strategic trader sells alongside the liquidator. When θ = 0.96, *as well as for all smaller values of θ*, the profit-maximizing strategic trader *buys* during the period when the liquidator sells, thereby absorbing a portion of the liquidator’s order imbalance. Further, for the same set of parameter values, the liquidator’s proceeds are *larger* when the strategic trader is present than when the strategic trader is absent.

We next assess outcomes when the strategic trader can also transact before the liquidator. Here, we see that the profit maximizing strategic trader acts as a liquidity supplier, in the sense that she buys during the day when the liquidator sells, for all values of θ. Depending on market resiliency, the strategic trader absorbs between 33% and 46% of the liquidator's sales in the "during" interval. In addition, the strategic trader follows a strategy that might casually be referred to as frontrunning, in the sense that she sells during the period preceding the liquidator's sale for all values of θ. However, the liquidator receives *higher* proceeds in the presence of the strategic trader as compared to the base case without strategic trading for all values of θ less than 0.94. The improved proceeds accrue because the strategic trader essentially provides additional competition for the limit order book during the liquidation period. The strategic trader's actions reduce liquidator proceeds *only* when θ approaches one, i.e. as price impacts of the trades in the preceding period become permanent, and therefore adversely affect prices during the liquidation period.

Figures 5A and 5B display period-by-period trade prices around the 20 unit liquidation, for market resiliency parameters, θ, of 0.0 and 0.98, respectively. Outcomes for intermediate resiliency parameters are generally similar – only when θ approaches 1 are the effects altered. The first third of the individual observations pertain to the pre-liquidation day, the second third pertain to the during-liquidation day, and the final third pertain to the post-liquidation day.

Figure 5A applies when the market is fully resilient ($\theta = 0$). The value of the liquidated asset decreases from \$100 to \$99.70, due to the permanent price impact of the liquidation. In the absence of strategic trading, the price remains at 100 until the liquidation begins. The price drops immediately to \$99.68 as the liquidation begins due to temporary price effects, and continues to decline to \$99.39, as the liquidation is completed. After the liquidation is completed the price returns to its new equilibrium.

Notably, strategic trading *reduces* price impacts. This occurs because the strategic trader absorbs a portion of the sales during the liquidation, and shifts the selling pressure to the preceding day. As a consequence overall price impact is reduced. The lowest price observed in any period with strategic trading is \$99.47, compared to a minimum price of \$99.39 without strategic trading.

Figure 5B applies when $\theta = 0.98$, implying that 98% of the temporary price impact in a given period persists to the next period. Price impacts are greater in the less-resilient market. In the absence of strategic trading the price is pushed as low as \$92.27, before recovering. In contrast, in the presence of the strategic trader the lowest price observed in any period is \$92.75. In general, as the market becomes less resilient (as θ increases) over the range θ = 0.00 to 0.98 the price impact of the liquidation increases, but is always smaller with strategic trading than without. Further, over the range θ = 0.00 to 0.94 liquidator proceeds are *larger* with strategic trading than without. Only when θ approaches 1, i.e. as the market loses all resiliency, does strategic trading magnify price impacts or reduce liquidator proceeds.

The results here therefore confirm those of Brunnermeier and Pedersen, but show that their central results are specific to their assumed structure. In particular, the strategic trader causes the price to overshoot its long term equilibrium and reduces the liquidator's proceeds *only* when the market is non-resilient, i.e. when trades price impacts are permanent or very nearly so. In contrast, in a resilient market the profit maximizing strategic trader will choose to absorb a portion of the liquidator's order imbalance during the liquidation period, and thereby reduces the price impact of the liquidator's order imbalance.

These insights are relevant to ETF crude oil rolls. There is little reason to think that such rolls convey private information that would lead to permanent changes in crude oil prices. Further, the crude oil futures markets are very active: on roll days an average of 777 front-month contracts trade each minute. If the limit order book refills quickly after order imbalances, i.e. the market is resilient, the liquidator benefits from the presence of a strategic trader who anticipates the liquidation. In the next section we report empirical evidence regarding the resiliency of the crude oil market.

The model is relevant beyond the present setting as well, since it implies that even a monopolist strategic trader improves market quality when trades' price impacts are not permanent. It might be questioned whether forced liquidations are associated with permanent price impacts, as the Brunnermeier and Pedersen model assumes, since they are not motivated by private information. Our model implies that traders should be concerned about potential predation mainly when their trades are motivated by private information that will affect long-run security value, or when the market is sufficiently non-resilient that the price impact of prior-period trades persists almost fully into the liquidation period.

V. Estimating the Resiliency of the NYMEX Crude Oil Market

The analysis is the preceding section underscores that the incentives of a strategic trader who becomes aware of the trading intentions of another large investor depend crucially on whether the price impact of trades is permanent or temporary, and in the case of temporary price impacts, on the resiliency of the market. To assess strategic trader incentives and price impacts around ETF rolls therefore requires estimates of trades' permanent and temporary price impacts, as well as market resiliency, in the NYMEX crude oil markets.

Guided by expression (1) we estimate these parameters with geometric lag regressions of the form:

$$P_t - M_1 = \alpha + \gamma \sum_{j=t-k}^{t} \theta^{t-j} q_j + \lambda \sum_{j=1}^{t} q_j^* + \varepsilon_t \qquad (12)$$

where P_t is the time t trade price, M_1 is the quote midpoint at the beginning of trading day (9:00 A.M. New York time), q_j is the signed order imbalance at time j, and q^*_j is the residual from a fifth-order auto-regression of q_j. The use of q^*_j instead of q_j to estimate the permanent price impact of order imbalances follows Madhavan, Richardson, and Roomans (1997) and Huang and Stoll (1997), and accommodates positive autocorrelation in order imbalances. The choice of the fifth-order auto-regression specification follows Sadka (2006). We implement (12) using time periods defined as either one or five seconds.[19]

Table 4, Panel A presents parameter estimates obtained using five second time intervals, and sixty lags of signed order imbalance. We report results for the front and second-to-maturity contracts, and for the full sample as well as separately for roll and non-roll days. While we are primarily interested in assessing the resiliency of the crude oil futures markets, it is also of interest to compare parameter estimates across roll and non-roll days. Consistent with results reported on Table 1 and Table 2, the coefficient estimates based on the pooled sample of roll and non-roll days indicate that the front contract is more liquid than second contract. In particular, the front contract has smaller permanent price impact

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[19] For time periods with multiple trades P_t is measured as the last trade price during the time period, and q_j is measured as the net order imbalance (excess of buyer-initiated over seller-initiated trades, measured in contracts) during the interval. The geometric lag expression (equation 12) is implemented using NYMEX order data by Generalized Method of Moments (GMM), using SAS Proc Model with a Bartlett Kernel set equal to the lag length plus one.

(5.6 cents versus 8.4 cents), smaller temporary price impact (2.1 cents versus 5.7 cents) and is more resilient (0.959 versus 0.982).

The parameter estimates for roll and non-roll days provide some evidence of market stress on roll days. The estimated temporary price impact is larger on roll days (0.038 vs. 0.020 for the front contract), as is the estimated resiliency parameter (0.986 vs. 0.959 for the front contract). However, the standard errors of the estimates are sufficiently large that differences in estimates across roll and non-roll days are not statistically significant.[20] Note also that these results need not imply reduced liquidity supply on roll days, as the roll brings heightened liquidity demand to the market.

The estimated permanent price impact for trades in the front contract is lower on roll days than on non-roll days (5.4 cents versus 5.8 cents), and the difference is statistically significant (p-value = 0.03).[21] A decrease in permanent price impact is consistent with the reasoning that ETF roll trades are viewed as uninformed. It may be surprising that the estimated permanent price impact on roll days is positive, if ETF rolls comprise non-informed trading. However, while ETF trades are large, they still comprise a minority of trading activity on roll days, and informed traders may be present. The model of Admati and Pfleiderer (1988) implies that informed traders may in fact prefer to trade at times when liquidity traders are also more active, in order to camouflage their trades and take advantage of reduced price impacts. Consistent with the reasoning, the estimated permanent price impact of trades in the second-nearest-to-delivery contract is actually larger (0.149 vs. 0.082) on roll than non-roll days.

Recall that the resiliency parameter, θ, measures the proportion of the temporary price impact attributable to current interval order imbalance that persists to the next period. The analysis in Section IV shows that the resiliency parameter is crucial in assessing the trading patterns that will maximize strategic trader profits. The estimates of θ reported on Table 4 uniformly exceed 0.95. At first glance

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[20] We also estimate expression (12) over one-second rather than five-second time intervals, with results that are generally similar to those discussed (Table 4, Panel B). Consistent with results of the 5-second specification, the estimated temporary price impact for the front contract increases (p-value of difference = 0.12) and market resiliency declines (the θ estimate increases) on roll days (p-value of difference = 0.07).

[21] Note that the price impact is estimated based on the surprise order imbalance rather than the level of the order imbalance. The ETF rolls studied here involve an average of over 20,000 contracts, but the large size of this imbalance is not a surprise to market participants. For this reason the estimated permanent price impact does not map directly into the Section IV theory, which did not allow for predictable order imbalances.

these estimates may appear to imply a non-resilient market. However, the estimates must be interpreted in light of the time interval that defines a period. We estimate expression (12) over short five second intervals to increase the effective sample size. Focusing on the front-month resiliency estimate of 0.959, for example, the estimated proportion of the temporary impact that persists after one minute is $0.959^{12} = .605$, the proportion that persists after five minutes is $0.959^{60} = .081$, the proportion that persists after ten minutes is $0.959^{120} = .007$, and the proportion that persists after 15 minutes is $0.959^{180} = .0005$. Stated alternately, these estimates imply that over 90% of the temporary price impact caused by an order imbalance is reversed within five minutes, and 99.95% is reversed within fifteen minutes, indicating that the crude oil futures markets are indeed quite resilient.[22]

Among the θ estimates reported in Panel A of Table 4, the one that implies the *least* resilient market is the 0.993 estimate obtained for the second-nearest-to-expiration contract on roll days. A resiliency estimate of 0.993 for five second intervals implies that less than 30% ($0.993^{180} = 0.283$) of the temporary price impact persists for fifteen minutes. The numerical illustrations of the theoretical analysis presented in Section IV are calibrated to a fifteen minute period. The empirical estimates obtained here therefore indicate that resiliency parameters of 0.3 or less at a fifteen minute interval are relevant in evaluating trader incentives. As noted, our analysis predicts that resiliency parameters less than about 0.96 imply that a profit maximizing strategic trader will elect to effectively provide liquidity to a known liquidation, by trading in the opposite direction during the liquidation period.

VI. Account-level analysis

The model presented by Brunnermeier and Pedersen (2005) implies predatory trading around any large and predictable liquidation. However, Boyd, Harris and Nowak (2011) indicate that predatory trading did not occur around the time of a well-publicized hedge fund liquidation. We now present specific analysis as to whether predatory strategies are observed at the time of the large liquidity-

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[22] These estimates are broadly consistent with those reported by Marshall, Nguyen and Visaltanachoti (2011), who examine large trades in the crude oil futures front contract, and estimate that around 65% of the impact on the bid-ask spread and over 80% of the impact on bid and ask depth are reversed within five minutes.

demanding trades associated with crude oil ETF rolls, by assessing strategies followed by individual trading accounts.

The CFTC data identifies the trading accounts associated with both the buy and sell side of each transaction. In the main analysis, which we refer to as the "long window," we define the "During" interval as 9 A.M. to 4:15 P.M. New York time on the ETF roll day, while the "Before" interval covers from midnight on Day -3 (three trading days prior) to 9 A.M. on roll day, and the "After" interval is the reopening of trading at 5 P.M. on the roll day through Midnight on Day +3 (three trading days after) the roll day. We also analyze a shorter window where the "During" interval is defined as the two-minute settlement period on the roll day, and the "Before" and "After" intervals are defined as the one hour of trading before and after, respectively, the settlement period. The "During" interval in the long window analysis is the day of the roll, while the "During" interval in the short window analysis is the two-minute period of trading that determines the ETF's benchmark price for the roll day.

The theoretical analysis focuses on a strategic trader who does not ultimately absorb any portion of the liquidator's position. Since strategic traders might also transact for reasons unrelated to the roll, we relax this definition for the empirical implementation. Specifically, we identify an account as potentially being a strategic trader if the absolute value of the net change in the account's inventory as a fraction of the account's total activity in the days surrounding the roll is less than 0.25. The ETF's natural counterparties (i.e., accounts that hold or can be induced by price concessions to hold opposite positions as the ETF) are unlikely to be classified as strategic traders, since their inventory change to total trading ratio is likely to exceed the threshold of 0.25.[23]

We categorize each account identified as a possible strategic trader as following one of twelve possible trading strategies, as described in Panel A of Table 5. Those strategic traders whose signed position change in the "During" interval is of the opposite sign as the ETF's order flow are deemed to be effectively following liquidity provision or sunshine strategies, labeled ST1 to ST5. Those strategic

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[23] As an illustration, suppose an account sells 1,000 contracts before, sells 1,000 contracts during, and buys 1,500 contracts after the roll. The absolute value of net change in account's inventory is 500 contracts, while total trading activity is 4,500 contracts. Since the ratio (500/4500) = 0.11, we classify the account as a strategic trader.

traders whose signed position change in the "During" interval is in the same direction as the ETF order flow are, consistent with the analysis of Brunnermeier and Pedersen (2005) deemed to be following potentially predatory strategies, labeled ST8 to ST12. The categories ST6 and ST7 represent accounts without any trading activity on the roll day.

We further categorized strategic traders into five sub-strategies within liquidity provision (ST1-ST5) and predatory trading (ST8-ST12) categories based on the account's trading before and after the roll day. For example, among sunshine traders, an account that trades in the opposite (same) direction as the ETF in the before interval and trades in the same (opposite) direction as the ETF in the after interval is placed in category ST1 (ST3). Our objective in identifying the sub-categories is to assess the relative importance of strategies implied by various theories. The Brunnermeier and Pedersen (2005) predatory trading strategy involves no trading before, trading the same direction as the ETF during, and trading opposite the ETF in the after period, which we label ST11. Our analysis in Section IV above implies that the strategic trader will trade in the same direction as the ETF in the "Before" period and in the opposite direction as the ETF in the "During" period (ST3, ST4, and ST5). Further, for resiliency parameters, θ, less than about 0.3, which the empirical estimates in Section V indicate to be relevant, the strategic trader will trade in the opposite direction as the ETF in the after period (ST3).[24]

To assess whether particular strategies are used more frequently around the ETF roll as compared to other periods, we estimate trading activity for each of the strategies on all usable non-roll days. A non-roll (control) day is usable for the long window analysis if the interval three days prior to three days after does not overlap with the three days prior or after an actual USO roll day. To identify abnormal activity, we compare the trading volume associated with a strategy on roll days benchmarked against that observed for the same strategy on control days.

Having assigned each strategic account to one of the 12 strategies at each roll period, we aggregate the *strategic volume* across all trading accounts associated with a strategy, where the strategic volume is

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[24] As a robustness check, we implement an additional screen where an interval is classified as 'no trade' if the account's trading activity in the interval as a percentage of the account's total trading activity across intervals is lower than the absolute value of 10%. Results are similar to those reported in Table 5.

simply the round trip volume associated with an account surrounding the roll.[25] Note that for each identified strategy there is a complementary strategy involving opposite trading patterns. For example, ST1 and ST12 are complimentary, in that ST1 involves trading against, against, and with the ETF during the three intervals, while ST12 involves the opposite pattern of trading with, with, and against the ETF during the three intervals. Since some strategies might be more common than others for reasons entirely unrelated to the ETF roll, we focus on *normalized strategic volume*, which is the strategic volume in a category less the strategic volume in the complementary strategy.

In Panel B of Table 5 we first report regression coefficients obtained when normalized strategic volume in categories ST1 to ST6 for all days (roll and control days) based on the long window is regressed on an indicator variable that equals one for USO roll days.[26] Increases in normalized strategic volume for categories ST1 to ST5 at the roll (positive coefficient on the roll day) would indicate increased use of sunshine strategies, while decreases in normalized strategic volume for categories ST1 to ST5 at the roll would indicate increased use of predatory strategies.

Several results from the long-window analysis are noteworthy. First, the statistically significant intercepts in regressions for ST3 and ST4 for the front contract imply that strategic trading in category ST4 is more prevalent and in ST3 less prevalent relative to complementary strategies on non-roll days. Second, we estimate statistically significant positive coefficients on the roll day indicator in regressions for ST3 for both contracts, and significant negative coefficients on the roll day indicator in regressions for ST1for both contracts. Since ST1 and ST3 are both liquidity providing strategies the results may appear to conflict. Note, though, that ST3 involves trading in the same direction as the upcoming ETF trades prior to the roll, while ST1 involves trading the opposite direction prior to the ETF roll. The analysis presented in Section IV and illustrated in Table 3 indicates that the profit maximizing strategy always involves (for any resiliency parameter) trading the same direction as the ETF in the period prior to the

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[25] Building on the illustration above, the strategic volume for an account that sells 1,000 contracts before, sells 1,000 contracts during, and buys 1,500 contracts after the roll is 1,500 contracts.

[26] Note that results for strategies ST7 to ST12 would simply be the opposite of results for ST1 to ST6, since they are the complements of the first six strategies.

roll, as in ST3, ST4, and ST5. Further, Table 3 indicates that the most profitable strategy involves trading opposite the ETF in the period after the ETF roll if the market is resilient, when θ is less than about 0.3. That is, for resiliency parameters in line with the empirical estimates reported in the preceding section, ST3 is indeed the more profitable strategy. These results are therefore consistent with a substitution by strategic traders toward the most profitable liquidity provision strategies around the time of the USO roll.

In Panel B of Table 5, we also report results obtained when strategic trading is classified into strategies over a short window. The most notable result is that, for both the front and second contract, we estimate a large positive roll day coefficient for ST1. Collectively, the coefficients suggest that strategic traders are trading in the opposite direction of the ETF both in the hour before and during the two-minute settlement window on roll day and reversing the position in the hour after the settlement period. To the extent that USO's TAS counterparties offset their TAS positions before and during the settlement period, the results suggest that the strategic traders identified in the short window act as liquidity providers and absorb the imbalance. Further, strategic traders are less likely to trade in the same direction as the ETF in the hour before the settlement window.

Overall, the results of our study indicate that the NYMEX oil futures market is resilient, with temporary price impacts of trades being fully reversed within minutes of an order imbalance shock. Evidence based on limit order book depth, quoted spreads, and effective spreads, are also consistent with increased competition from liquidity providers on the roll date. Further, the results of this analysis of trading by individual accounts also points towards increased liquidity provision around the roll.

Estimates reported in Table V indicate that order imbalances do have a permanent price impact, even around the roll. A strategic trader who provides liquidity by absorbing order imbalances during the roll must offset the inventory (by trading in the same direction as the roll) either before or after the roll. Given long-lived price impacts it is more profitable to conduct offsetting trades ahead of (as in ST3 or ST4) than after (as in ST1 or ST2) the roll. Our analysis implies that ST3 will be the most profitable strategy, and the long window evidence supports that strategic traders indeed provide liquidity at the roll while using this strategy.[27] Importantly, our analysis also indicates that the temporary price impacts associated with the large trades are reduced and the liquidator (ETF) proceeds are enhanced by strategic trading of this type. This stands in contrast to the implications of the Brunnermeier and Pedersen (2005) model, which would have predicted larger price impacts and decreased liquidator (ETF) proceeds.

VII. Explaining Crude Oil ETF Stock Price Performance – Trading Costs and Storage Costs

The analysis reported here provides little evidence that strategic traders engage in predatory strategies of the type described by Brunnermeier and Pedersen (2005) around USO rolls. This result is consistent with the theoretical analysis presented here implying that strategic traders have incentives to trade in a more benign manner in a resilient market. It is also consistent with the reasoning that the pre-announcement of the roll attracts additional liquidity providers, as in the sunshine trading theory of Admati and Pfleiderer (1991). What then explains the under-performance of USO stock (the largest of the crude oil ETFs) compared to the level of crude oil prices, as documented in Figure 1?

The following insights apply. First, USO was not designed to deliver returns that track changes in the level of crude oil prices, but rather changes in prices of individual futures contracts. Second, investors who hold spot crude oil also fail to earn net returns that match the change in spot prices, as they incur costs of storing the crude oil.[28] Third, even in the absence of predation and in the presence of sunshine traders, it can be anticipated that a large demander of liquidity will pay some cost to execute their trades.

a. Ex post Return Premia and Storage Costs

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[27] To expand on this reasoning, note that the ETFs (or the TAS counterparties of ETF) actively sell the front contract and actively buy the second month contract on the roll day. The positive permanent price effect implies that ETF trading would cause front contract prices to decrease and second contract prices to increase on the roll day. For this reason, strategic liquidity providers in front month contracts are better off building a short position (at higher prices) before the roll day. Along similar lines, strategic liquidity providers in the second month contracts are better off building a long position (at lower prices) before the roll day.

[28] Indeed, crude oil ETFs take positions in futures contracts rather than hold barrels of physical crude oil to avoid incurring such storage costs. In contrast, ETFs designed to deliver returns that depend on the prices of commodities with lower storage costs (e.g. precious metals) often hold physical inventories. For example, the Wall Street Journal reported that the SPDR Gold Shares ETF holds over 41 million troy ounces of physical gold inventory. See http://blogs.wsj.com/marketbeat/2012/03/02/etfs-hold-more-gold-than-italy-france/.

We formalize these arguments and quantify their relative importance as follows. Let P_t denote the date t spot price and $F_t(m)$ denote the date t futures price for delivery at date t+m. Futures prices are linked to spot prices by the no-arbitrage "cost-of-carry" relation:

$$F_t(m) = P_t e^{S_t m}, \tag{13}$$

where S_t is the marginal investor's continuously compounded per-period cost of carrying inventory, including forgone interest and other storage costs. Non-interest storage costs include costs of renting storage tanks, insurance, etc., and may at times be offset in part or full by "convenience yields" that reflect the option value of holding inventory. Applying (13) to futures for delivery at dates t+m and t+n, the per-period cost of carrying inventory can be inferred as:

$$S_t = \frac{\ln(F_t(m) / F_t(n))}{(m-n)} \tag{14}$$

which implies that the marginal cost of carrying inventory is revealed by the slope of the futures term structure. Using expression (14) with the daily EIA data, we compute the cost of storage implied by the settlement prices of the first and second nearest-to-expiration crude oil contracts for each trading day from January 1, 1999 to December 31, 2013, and report the results on Table 6, for the full sample and for subsamples. We focus in particular on the subsample beginning April 10, 2006, when USO was launched. For the full sample the mean implied storage cost (multiplied by 250 to convert to an annual equivalent) is 0.49%. In contrast, during the post-USO subsample the mean implied storage cost was 12.38%, with an associated t-statistic of 22.22. A positive term slope, whereby futures prices rise for more distant delivery dates, characterizes what practitioners refer to as a "contango" market. The cost-of-carry relation implies that contango will be observed only when net storage costs for the marginal holder of inventory are positive.[29]

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[29] Pirrong (2011) documents that the collapse in crude oil prices during the recent financial crisis was accompanied by large increases in physical crude oil inventories and in the marginal cost of carrying inventory. To see that the positive term slope represents marginal storage costs, recognize that S_t also represents the pre-storage-cost daily return to a strategy of purchasing crude oil for delivery at date t+n at price $F_t(n)$ and simultaneously selling the same oil for delivery at date t+m at price $F_t(m)$. Positive arbitrage profits are available if oil can be stored from date t+n to date t+m for a per-period cost less than S_t. Of course, the no-arbitrage condition applies to the *marginal* holder of inventory. Those who can store a commodity for lower cost can earn profits. Anecdotal

Define an ex post spot return premium as:

$$U_{t+1} = \ln\left[\frac{P_{t+1}}{P_t e^{S_t}}\right]. \tag{15}$$

The denominator of expression (16) is the time t spot price adjusted for the cost of storing oil for one period, so U_{t+1} is interpreted as the return in excess of storage costs (analogous to the return in excess of the interest rate often studied in equity markets). We construct a daily time series of spot prices implied by expression (13), relying on the nearest-to-expiration futures price and the previously computed daily storage cost estimates. From this series we compute the time series of realizations of U_t. Table 6 reports mean outcomes, annualized by multiplying by 250.

For the full sample, the spot return premium for crude oil is 5.46% per year. During the 1990s, the spot return premium was 4.81% per year. In the period before USO was launched, January 2000 through April 9, 2006, the spot return premium surged to 22.80% per year, potentially whetting investor demand for products linked to crude oil prices. In contrast, since USO's April 10, 2006 launch, the mean spot return premium was -7.64% per year. While none of these means are statistically significant (reflecting the high variability of price changes), the accumulated effect is nevertheless economically important. The negative spot return premium for the period when USO was active implies that the appreciation of spot oil prices during the sample period was considerably *less* than sufficient to compensate for the marginal cost of carrying inventory.

Applying expression (13) at dates t and t+1 and denoting $\Delta S = S_{t+1} - S_t$, the one-period return to a long position in a given futures contract can be expressed as:

$$\ln\left[\frac{F_{t+1}(m-1)}{F_t(m)}\right] = U_t + (m-1)\Delta S, \tag{16}$$

while, by comparison, the continuously compounded growth in the spot price can be written as:

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accounts (e.g. http://blogs.reuters.com/great-debate/2010/07/22/contango-and-the-real-cost-of-carry/) indicate entry by non-traditional firms (e.g. hedge funds) into the oil storage business in recent periods.

$$\ln\left[\frac{P_{t+1}}{P_t}\right] = U_t + S_t \,. \tag{17}$$

Comparing expressions (16) and (17) yields several insights. First, and most important, for a given cost of carry ($\Delta S = 0$), the rate of appreciation in the spot price exceeds that of the futures price by S_t, the cost of carrying inventory. Stated alternately, spot price appreciation will exceed changes in prices of individual futures contracts in contango markets, and vice versa in "backwardated" markets (where the implied cost of carry is negative, presumably due to large "convenience yields"). As noted, the marginal cost of carry was large and significant (12.4% per year) during the USO sample period, implying underperformance of long futures positions relative to spot price changes.

Second, the cost-of-carry itself has no direct implication for futures returns, as S_t does not appear in expression (16).[30] In particular, the fact that the rolling a futures position in a contango market involves buying the second contract at a price higher than the selling price for the expiring contract has no direct implication for futures returns, which reflect only *changes* in prices during periods that positions are held.[31] Third, the futures return does depend on ΔS. Finally, both futures and spot returns are equally affected by U_t, the ex post premium in the spot price.

b. Trade Execution Costs

The preceding analysis shows that it is to be anticipated that USO returns trailed the growth of spot prices in light of positive storage costs. But did costs related to their predictable roll trades also contribute? To shed some additional light on this issue, we compute daily time series of futures returns, $\ln(F_{t+1}(m-1)/F_t(m))$. The preceding expression applies to futures prices for a contract with a fixed

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[30] However, expression (18) does not rule out covariation between the cost of carry and futures returns, which has in fact been documented in a number of commodity markets. See, for example, Liu and Tang (2010), Szymanowska, De Roon, Nijman, and Van den Goorbergh (2014), and the papers referenced therein. The data reported on Table 6 are consistent with negative covariation, in that futures returns are positive and the cost of storage negative during the January 2000 to April 2006 period, while futures returns are negative and the cost of storage positive during the April 2006 to December 2013 period.

[31] In contrast, the financial press and some academic authors have incorrectly asserted that a roll trade in a contango market generates an immediate loss. For example, Mou (2011) claims (page 13) that the excess of the front month futures price over the more distant-delivery futures price "is the amount of gain (or loss) per unit of the commodity when rolling futures forward" and asserts (page 2) that futures investors earn a "return called 'roll yield', which refers to the difference between log price of the maturing contract they roll from and the deferred contract they roll into."

delivery date, t+m. To compute a continuous time series of futures returns requires linking return series as contracts mature.

We compute three time series of daily futures returns (see Figure 2). The first is the return to the front month contract, computed based on the current and prior day price of the front month contract, for all days including the last day of trading for the expiring contract. The second is the return to the second nearest contract, computed based on the current and prior day price of the second month contract, for all days including the last day of trading for the expiring contract. The third, denoted "Benchmark Return" is based on settlement prices that comprise USO's benchmark and that reflect its roll strategies. The Benchmark return equals the return on the front month contract in the days before USO rolls and equals the return on the second month contract after USO completes its roll.[32] As noted, USO rolls using TAS contracts, and its trades are executed at the relevant settlement prices. Trade execution costs arise in the form of adverse changes in settlement prices, i.e. increases in the price of the second contract and/or decreases in the price of the front contract, attributable to the roll. Such costs can potentially arise due to predation, or alternatively because of imperfectly elastic liquidity supply.

Table 6 reports mean (x250) daily returns on the three futures return series, for the full sample as well as for the USO period. For the latter interval we also report the mean continuously compounded return to the USO ETF. Each mean return is negative during the USO period. The mean Benchmark futures return is -8.79% per year. By comparison, the mean return to the front month contract is -5.63% per year and the mean return to the second month contract is -5.80% per year. The benchmark return is 3.16% per year less than the return to the front contract and is 2.99% less than the return to the second contract. The latter differential is statistically significant (t-statistic = -2.48).[33]

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[32] USO completed its roll on a single day through February 2009, after which it shifted to a four-day roll (see http://www.bloomberg.com/apps/news?pid=newsarchive&sid=aZYy1UXKZRb0). The Benchmark return is equal to the front month contract return on roll days through February 2009. Thereafter, the benchmark return is a weighted average of the return on the front month and second month contracts during the four days of the roll, with the weight on second month return equal to 0, 0.25, 0.50, and 0.75 on the four consecutive days of the roll.

[33] That the former is not significant reflects the greater volatility of the Return 1 series, which in turn reflects in part the high volatility in the settlement price of the expiring contract on the final trading day.

The prices that comprise the benchmark return are potentially affected by the USO roll. Note that the second month return and the benchmark return are identical in the days after USO completes its roll. The statistically significant differential in the second month futures return relative to benchmark returns therefore reflects better performance of the second month contract relative to the front month contract, i.e. widening of the calendar spread between the second- and the front month contract prices, in the days before and during the USO roll. The differential of 2.99% per year equates to a widening of the calendar spread ahead of the roll that averages 25 basis points, and comprises an estimate of USO's trading costs associated with the roll.[34] Analogously, the excess of the front month return over the benchmark return reflects better performance of the front month contract relative to the second month contract, i.e. narrowing of the calendar spread, in the days after the completion of the USO roll. This differential of 3.16% per year equates to 26 basis points per roll, and comprises an additional (though noisier) estimate of the roll cost.

These estimates of ETF roll trading costs are not particularly large as compared to estimated costs for institutional trades in U.S. equities in recent years. For example, Anand, Irvine, Puckett and Venkataraman (2012) report that institutional trading costs in large-capitalization equities average around 15 to 20 basis points one way, or 30 to 40 basis points round trip. The average institutional order size in their sample is around 1.5% of average daily volume (ADV) in the stock, while the ETF rolls in our sample are as large as (Table 1) 13% of daily volume for the front month and 18% for the second month, and often exceed 100% of market volume during the two minute settlement period whose price they seek to match. That estimated trade execution costs are moderate despite the sharp demand for liquidity associated with the rolls reflects the resiliency of the crude oil futures market, and the effectiveness of the "sunshine trading" strategy, where preannouncement attracts liquidity suppliers, including strategic traders, as well as natural counterparties.

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[34] The same comparison during the 1/1/00 to 4/9/06 period gives an estimated roll cost of 4.57% per year, or 38 basis points per roll. USO was not active during this period, but index funds tracking the Goldman Sachs Commodity Index were (see Mou (2011)). In contrast, the Return2 and Benchmark return means are almost identical during the 1990s, before index trading became popular.

c. Oil Prices and USO ETF Returns.

We summarize this analysis as follows. The mean annualized return (daily mean x250) to the USO ETF during the April 10, 2006 to July 31, 2012 period was -8.42%, while the mean annualized rate of change in implied spot prices during the same period was 4.74% (Table 6). This gives rise to the perception, reinforced by Figure 1, that the USO ETF performed very poorly. The perceived underperformance has been attributed to predatory trading or to the effect of "contango" on futures prices. We show that neither of these explanations is relevant.

The most important factor is storage costs, which for the marginal investor averaged 12.38% per year during this period. The actual post-storage-cost return to the marginal investor holding spot crude oil was therefore -7.64% per year. Crude oil futures markets as a whole performed somewhat better – a long position rolled so as to always remain invested in the second (front) month contract earned -5.80% (-5.63%) per year. The USO benchmark, which reflected the price impacts of the actual USO roll strategies, performed worse, delivering -8.79% per year. We attribute the underperformance of the USO benchmark relative to hypothetical long futures strategies invested in the front or second month contract to trade execution costs that average about 25 basis points per roll. Finally, the actual USO ETF return of -8.42% per year slightly exceeds the benchmark futures return of -8.79%, reflecting that USO can invest its cash balances. Interestingly, USO's actual return, which incorporates the effect of management fees, interest, roll costs, and changes in the cost-of-carry, is slightly superior to the average post-storage cost spot crude oil return premium of -7.64% per year earned by the marginal holder of crude oil inventory.

We conclude that USO's stock performance can be well explained by the combination of crude oil storage costs and moderate trade execution costs. That estimated trade execution costs are modest even though USO demands a large quantity of liquidity is consistent with the theory of sunshine trading, and provides little or no evidence that harmful predatory trading occurs in the context of ETF rolls.

VIII. Conclusions

In this paper, we study trading strategies, liquidity, and price patterns around the time of large and predictable monthly trades undertaken by the US Oil ETF, which is designed to provide returns that track changes in crude oil futures prices. USO demands a large amount of liquidity. Aggregated across the twelve roll dates in our sample period, net roll activity comprises approximately 5% of roll-day volume in the front contract and 9% of roll-day volume in the second contract. Further, USO typically seeks to trade at the daily settlement price, which is established in a two-minute period, and their roll trades on average exceed market wide volume during this interval. We view the large and predictable liquidity demand associated with the USO roll to comprise an ideal experiment for testing the implications of two relevant theories: predatory and sunshine trading, in a setting where both potentially apply.

In addition to presenting empirical evidence, we develop a simple model that extends prior models to consider the implications of strategic trading in a resilient market. We find that the implications that the strategic trader causes prices to overshoot and reduce liquidator proceeds only hold when trades' price impacts are permanent or long-lasting. When markets are resilient, the model predicts that the strategic trader will choose to act as a liquidity provider, absorbing a portion of the liquidator's order imbalance on roll day, while offloading the resulting inventory in periods before or after the roll day. Further, for the same set of parameter values, the liquidator's proceeds are *larger* when the strategic trader is present than when the strategic trader is absent. The extended model is relevant to crude oil ETF rolls, as well as other settings where price impacts are temporary rather than permanent.

We estimate the resiliency of the crude oil markets, and find that the market is indeed quite resilient. Based on our estimates, virtually all of the temporary price impact caused by an order imbalance is reversed within 15 minutes. However there is some evidence that the market is marginally less resilient and temporary price impacts are marginally larger on ETF roll days than non-roll days.

We estimate that USO effectively pays about 25 basis points on average to complete its roll trades. While this cost is non-trivial, it is not large relative to institutional trading costs in large-capitalization equities. Observing moderate trading costs despite the ETF's large and concentrated demand for liquidity reflect the resiliency of the crude oil futures market, and the effectiveness of the "sunshine trading" strategy where preannouncement attracts liquidity suppliers, including strategic traders, as well as natural counterparties. Still, accumulated trading costs of 3% per year are substantial. These costs arise from the large quantity of liquidity demanded by a strategy involving monthly rolls, and highlight the practical importance of implementation strategies for funds seeking to match benchmark returns.

In light of the increasing popularity of ETFs in retail and institutional portfolios, regulators are interested in better understanding the impact of ETF activity on market quality of the underlying securities. Unlike (unlevered long) equity ETFs, which tend to be buy-and-hold investors, leveraged ETFs or those that invest in futures contracts have faced regulatory scrutiny because of their frequent large trades. With respect to USO's roll, we find little evidence that strategic traders engage in predatory trading that impairs price discovery and destabilizes the futures market. These results are consistent with the theoretical analysis presented here implying that strategic traders have incentives to trade in a benign manner in a resilient market, and are also consistent with the reasoning that the pre-announcement of the roll attracts additional liquidity providers and natural counterparties, as proposed by Admati and Pfleiderer (1988, 1991).

However, the optimal response of strategic traders depends on the market structure. Our model does not imply that predatory trading is never a concern. If trades are motivated by private information, or when trades are executed in less resilient markets where price impacts are closer to permanent, our model predicts that predatory strategies of the type described by Brunnermeier and Pedersen (2005) and Carlin, Lobo and Viswanathan (2009) are more plausible. In recent years, there has been a significant increase in agricultural- and industrial metal- tracking ETFs that invest in relatively less liquid commodity futures, such as copper, soybeans, and wheat. An analysis of the price effects and the strategic trading surrounding ETF rolls in less liquid futures markets remains an important area of future research.

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Table 1. USO and Market Trading activity on Roll Days

Reported are trading volumes (in contracts) in the NYMEX Crude Oil futures market for the full trading day, and during the two-minute settlement period, on USO roll days from March 2008 to February 2009. Also reported are the estimated sell and buy volumes attributable to USO's roll trading on these days. We rely on the Commodity Futures Trading Commission (CFTC) dataset to calculate the market-wide trading volumes for the full day and settlement periods. The CFTC dataset includes all completed trades in NYMEX crude oil futures, including floor and block trades, as well as trades completed on the GLOBEX electronic market. USO roll trading volume is estimated on the basis of USO's Total Net Assets (TNA) on the roll date relative to front and second month settlement prices on the roll day. Settlement prices are obtained from the Energy Information Agency (EIA). TNA values were provided by ALPS on behalf of USO. Roll dates are two weeks prior to the expiration of the nearest-delivery contract. A calendar schedule of USO's recent and future roll dates is available on the website: hhttp://www.unitedstatesoilfund.com/.

	Front Contract on Roll Date				Second Contract on Roll Date			
Roll date	**ETF Selling Activity (contracts)**	**Market Trading Volume (contracts)**	**ETF %**	**Market Trading Volume During Settlement**	**ETF Buying Activity (contracts)**	**Market Trading Volume (contracts)**	**ETF %**	**Market Trading Volume During Settlement**
3/5/2008	4,455	414,308	1%	16,756	5,362	205,827	3%	10,449
4/8/2008	5,632	307,800	2%	16,338	5,694	165,544	3%	15,775
5/6/2008	5,122	331,913	2%	11,933	5,139	129,110	4%	6,632
6/6/2008	8,779	508,749	2%	18,139	6,228	231,984	3%	11,112
7/8/2008	7,208	382,404	2%	15,378	8,055	154,453	5%	13,299
8/6/2008	6,289	307,994	2%	16,189	6,293	140,471	4%	13,489
9/8/2008	11,961	317,923	4%	18,581	11,439	142,644	8%	14,791
10/7/2008	9,119	342,917	3%	21,235	9,097	193,234	5%	15,414
11/6/2008	13,031	292,018	4%	6,756	14,665	87,869	17%	3,578
12/5/2008	23,725	327,140	7%	27,508	23,751	157,572	15%	22,765
1/6/2009	49,852	331,307	15%	9,145	42,409	183,802	23%	7,659
2/6/2009	67,882	518,382	13%	32,674	58,764	318,960	18%	29,187
Sum	213,055	4,382,855	5%	210,632	196,896	2,111,470	9%	164,150

Table 2. Average Market Quality Measures on USO Roll and non-Roll days

Reported are market quality measures on USO roll days and non-roll days in the NYMEX Oil Futures market. USO's roll dates are identified based on their publicly stated roll strategy. Panel A reports on market quality on roll days during the period March 1, 2008 to February 28, 2009. Non-roll days are defined as Days [-5,-2] before the roll day. Market quality is calculated each minute of the day and then averaged across roll and non-roll days. We rely on Commodity Futures Trading Commission (CFTC) data for calculating trading volume and number of liquidity providing accounts. Trading volume includes all completed trades in NYMEX crude oil futures, including floor and block trades, as well as trades completed on the GLOBEX. The spread, depth and imbalance measures are based on the Chicago Mercantile Exchange's Datamine database for GLOBEX electronic market. Trade imbalance is the signed difference between buyer and seller initiated volume standardized by subtracting the mean and dividing by the standard deviation of imbalance during the same minute (across roll and non-roll days). Quoted bid-ask spread (in basis points) is the difference between the lowest limit price for unexecuted sell orders and the highest limit price for unexecuted buy orders. Depth is the total volume of unexecuted sell (ask depth) and buy (bid depth) orders at prices within four ticks of the most competitive prices. Effective spread (in basis points) for a buyer (seller) initiated trade is twice the excess of trade price (quote midpoint) over the quote midpoint (trade price). Reported are Wilcoxon signed rank t-statistic and p-value with the null hypothesis of zero difference in median.

Panel A: Front and Second Month Contract – Roll and non-roll days

	Roll Period		**Non-Roll Period**			**Wilcoxon Signed Rank**	
	Mean	**Median**	**Mean**	**Median**	**Difference:**	**T-Stat**	**P-Value**
Panel A: Front and Second Month Crude Oil Futures Contract							
Front Month							
Trading Volume per Minute (contracts)	777.0	716.4	574.9	544.9	202.04	13.75	<.0001
Standardized Trade Imbalance	-0.023	-0.023	0.014	0.015	-0.04	-2.23	0.0129
Quoted Spread	1.13	1.12	1.17	1.15	-0.04	-3.97	<.0001
Effective Spread	1.96	1.83	2.03	1.97	-0.08	-3.97	<.0001
Quoted Spread	0.011	0.011	0.012	0.012	0.00	-3.97	<.0001
Near-inside Bid Depth (contracts)	52	51	48	47	4.33	10.98	<.0001
Near-inside Ask Depth (contracts)	49	48	45	45	3.97	11.38	<.0001
Liquidity Supplying accounts (N)	10,470	10,541	9,698	9,787	772.00	0.82	0.413
Second Month							
Trading Volume per Minute (contracts)	354.6	283.9	193.2	169.3	161.36	15.20	<.0001
Standardized Trade Imbalance	0.0020	0.0122	0.0099	0.0082	-0.01	-0.52	0.3015
Effective Spread	2.29	2.06	2.42	2.29	-0.14	-4.66	<.0001
Quoted Spread	1.42	1.39	1.52	1.48	-0.10	-6.99	<.0001
Near-inside Bid Depth (contracts)	24	23	22	21	2.25	9.80	<.0001
Near-inside Ask Depth (contracts)	20	20	19	18	1.96	9.07	<.0001
Liquidity Supplying accounts (N)	1416	1198	860	835	556.00	2.98	0.0028

Panel B: Longer maturity crude oil futures contracts on non-roll days

	Trading Volume per Minute		Quoted Spread		Near-inside Bid Depth (contracts)		Near-inside Ask Depth (contracts)		Effective Spread	
	Mean	**Median**	**Mean**	**Median**	**Mean**	**Median**	**Mean**	**Median**	**Mean**	**Median**
Panel B: Longer-Maturity Crude Oil Futures Contracts										
Contract Month 3*	78.21	73.34	1.54	1.50	29.74	27.48	12.21	11.92	2.53	2.28
Contract Month 6&	21.04	18.47	2.30	1.95	19.06	17.99	6.93	6.94	6.46	4.83
Contract Month 9^	7.24	5.53	5.15	4.09	14.75	13.57	5.37	5.45	8.66	5.96
Contract Month 12^	5.07	3.90	3.84	3.37	21.01	21.32	5.02	4.74	6.57	4.40

* results aggregated at one-minute; & results aggregated in five-minutes; ^ results aggregated at 10-minutes

Table 3. Strategic Trading around a known liquidation – Numerical Outcomes

Reported are the outcomes based on the strategic trader’s optimal choice of quantities to maximize profits (expression (13)). The initial price (V0) equal to \$100, N=32 periods within each interval, and the liquidation amount is 20 units. The parameter λ=0.015 implies that the cumulative permanent price impact is of the liquidation is 30 basis points. The column ‘LP’ refers to the liquidator’s proceeds for the 20 units. The columns ‘Pre’, ‘During’ and ‘After’ report the profit maximizing strategic trader’s order flow as a proportion of the liquidator sale, with positive values indicating trading in the same direction as the liquidator. The column ‘SP’ reports the strategic traders profit from expression (9). The column ‘AC’ reports the limit order traders’ (or natural counterparties) acquisition cost for the 20 units.

Table 4: Numerical Outcomes from Closed Form Solutions -- Strategic Trading Around a Known 20 Unit Liquidation, Lambda = .015, Gamma = 0.5

	Base	Optimal Unconstrained Strategic Trading						Optimal Strategic Trading, Constrained No Prior					
Theta	LP = AC	Pre	During	After	SP	LP	AC	Pre	During	After	SP	LP	AC
0.00	1990.7	0.40	-0.33	-0.07	1.8	1991.4	1993.1	0.00	-0.13	0.13	0.2	1991.9	1992.1
0.02	1990.5	0.40	-0.33	-0.07	1.8	1991.3	1993.1	0.00	-0.13	0.13	0.2	1991.8	1992.0
0.04	1990.4	0.39	-0.33	-0.06	1.8	1991.2	1993.0	0.00	-0.14	0.14	0.2	1991.7	1992.0
0.06	1990.3	0.39	-0.33	-0.06	1.8	1991.2	1993.0	0.00	-0.14	0.14	0.3	1991.6	1991.9
0.08	1990.1	0.39	-0.33	-0.05	1.8	1991.1	1992.9	0.00	-0.14	0.14	0.3	1991.5	1991.8
0.10	1990.0	0.38	-0.33	-0.05	1.8	1991.0	1992.8	0.00	-0.14	0.14	0.3	1991.4	1991.7
0.12	1989.8	0.38	-0.33	-0.04	1.8	1991.0	1992.8	0.00	-0.15	0.15	0.3	1991.3	1991.6
0.14	1989.7	0.37	-0.33	-0.04	1.8	1990.9	1992.7	0.00	-0.15	0.15	0.3	1991.2	1991.5
0.16	1989.5	0.37	-0.33	-0.04	1.9	1990.8	1992.6	0.00	-0.15	0.15	0.3	1991.1	1991.4
0.18	1989.3	0.36	-0.33	-0.03	1.9	1990.7	1992.6	0.00	-0.15	0.15	0.3	1990.9	1991.3
0.20	1989.2	0.36	-0.33	-0.03	1.9	1990.6	1992.5	0.00	-0.15	0.15	0.4	1990.8	1991.2
0.22	1989.0	0.36	-0.33	-0.02	1.9	1990.5	1992.4	0.00	-0.16	0.16	0.4	1990.7	1991.1
0.24	1988.8	0.35	-0.33	-0.02	1.9	1990.4	1992.3	0.00	-0.16	0.16	0.4	1990.5	1990.9
0.26	1988.6	0.35	-0.33	-0.01	2.0	1990.3	1992.2	0.00	-0.16	0.16	0.4	1990.4	1990.8
0.28	1988.3	0.34	-0.33	-0.01	2.0	1990.1	1992.1	0.00	-0.16	0.16	0.4	1990.2	1990.7
0.30	1988.1	0.34	-0.33	-0.01	2.0	1990.0	1992.0	0.00	-0.16	0.16	0.5	1990.0	1990.5
0.32	1987.9	0.34	-0.33	0.00	2.0	1989.9	1991.9	0.00	-0.17	0.17	0.5	1989.9	1990.4
0.34	1987.6	0.33	-0.33	0.00	2.1	1989.7	1991.8	0.00	-0.17	0.17	0.5	1989.7	1990.2
0.36	1987.3	0.33	-0.33	0.01	2.1	1989.5	1991.6	0.00	-0.17	0.17	0.6	1989.5	1990.0
0.38	1987.0	0.32	-0.33	0.01	2.1	1989.4	1991.5	0.00	-0.17	0.17	0.6	1989.2	1989.8
0.40	1986.7	0.32	-0.34	0.02	2.2	1989.2	1991.3	0.00	-0.17	0.17	0.6	1989.0	1989.6
0.42	1986.4	0.31	-0.34	0.02	2.2	1989.0	1991.2	0.00	-0.18	0.18	0.6	1988.8	1989.4
0.44	1986.0	0.31	-0.34	0.03	2.3	1988.8	1991.0	0.00	-0.18	0.18	0.7	1988.5	1989.2
0.46	1985.6	0.31	-0.34	0.03	2.3	1988.5	1990.8	0.00	-0.18	0.18	0.7	1988.2	1988.9
0.48	1985.2	0.30	-0.34	0.03	2.4	1988.3	1990.6	0.00	-0.18	0.18	0.8	1987.9	1988.7
0.50	1984.8	0.30	-0.34	0.04	2.4	1988.0	1990.4	0.00	-0.18	0.18	0.8	1987.6	1988.4
0.52	1984.3	0.30	-0.34	0.04	2.5	1987.7	1990.2	0.00	-0.19	0.19	0.9	1987.2	1988.1
0.54	1983.8	0.29	-0.34	0.05	2.6	1987.4	1989.9	0.00	-0.19	0.19	0.9	1986.8	1987.8
0.56	1983.3	0.29	-0.34	0.05	2.7	1987.0	1989.6	0.00	-0.19	0.19	1.0	1986.4	1987.4
0.58	1982.7	0.28	-0.34	0.05	2.7	1986.6	1989.3	0.00	-0.19	0.19	1.0	1986.0	1987.0
0.60	1982.0	0.28	-0.34	0.06	2.8	1986.2	1989.0	0.00	-0.19	0.19	1.1	1985.5	1986.6
0.62	1981.3	0.28	-0.34	0.06	2.9	1985.7	1988.6	0.00	-0.19	0.19	1.2	1984.9	1986.1
0.64	1980.5	0.27	-0.34	0.06	3.1	1985.2	1988.2	0.00	-0.20	0.20	1.2	1984.3	1985.5
0.66	1979.6	0.27	-0.34	0.07	3.2	1984.6	1987.8	0.00	-0.20	0.20	1.3	1983.7	1985.0
0.68	1978.7	0.27	-0.34	0.07	3.3	1983.9	1987.3	0.00	-0.20	0.20	1.4	1982.9	1984.3
0.70	1977.6	0.27	-0.34	0.07	3.5	1983.2	1986.7	0.00	-0.20	0.20	1.5	1982.1	1983.6
0.72	1976.4	0.26	-0.34	0.08	3.7	1982.3	1986.0	0.00	-0.20	0.20	1.6	1981.1	1982.7
0.74	1975.0	0.26	-0.34	0.08	3.9	1981.3	1985.3	0.00	-0.20	0.20	1.7	1980.0	1981.7
0.76	1973.4	0.26	-0.34	0.08	4.2	1980.2	1984.4	0.00	-0.20	0.20	1.8	1978.8	1980.6
0.78	1971.6	0.26	-0.34	0.08	4.5	1978.9	1983.4	0.00	-0.20	0.20	1.9	1977.4	1979.3
0.80	1969.6	0.26	-0.34	0.08	4.8	1977.4	1982.2	0.00	-0.20	0.20	2.1	1975.7	1977.8
0.82	1967.1	0.26	-0.34	0.08	5.2	1975.5	1980.8	0.00	-0.20	0.20	2.2	1973.7	1975.9
0.84	1964.2	0.27	-0.35	0.08	5.7	1973.3	1979.0	0.00	-0.20	0.20	2.3	1971.3	1973.6
0.86	1960.8	0.27	-0.35	0.08	6.3	1970.5	1976.8	0.00	-0.19	0.19	2.4	1968.4	1970.8
0.88	1956.6	0.29	-0.35	0.07	7.1	1966.9	1973.9	0.00	-0.19	0.19	2.4	1964.7	1967.1
0.90	1951.4	0.30	-0.36	0.06	8.1	1962.0	1970.1	0.00	-0.18	0.18	2.3	1959.9	1962.2
0.92	1944.9	0.33	-0.37	0.04	9.6	1955.1	1964.7	0.00	-0.16	0.16	1.9	1953.5	1955.4
0.94	1936.7	0.38	-0.38	0.00	12.1	1944.2	1956.3	0.00	-0.12	0.12	1.1	1944.1	1945.3
0.96	1926.1	0.48	-0.41	-0.07	17.5	1923.8	1941.3	0.00	-0.04	0.04	0.1	1928.7	1928.8
0.98	1912.2	0.74	-0.46	-0.28	36.2	1868.3	1904.4	0.00	0.22	-0.22	2.9	1893.0	1896.0
1.00	1893.8	16.17	-0.33	-15.83	1648.5	-1401.1	247.4	0.00	7.75	-7.75	386.7	1070.6	1457.2

Table 4. Regression estimates of permanent and temporary price impact and the resiliency of the market

Reported are estimates of the permanent price impact (λ), the temporary price impact (γ) and the resiliency of the market (θ) in the NYMEX crude oil markets for the full sample, and separately on USO roll and non-roll days. The analysis relies on trades and limit order book data from Chicago Mercantile Exchange's Datamine database on GLOBEX electronic market. USO's roll dates are identified based on their publicly stated roll strategy. Non-roll days are defined as Days [-5,-2] before the roll day. We estimate these parameters with geometric lag regressions of the following form:

$$P_t - M_1 = \alpha + \gamma \sum_{j=t-k}^{t} \theta^{t-j} q_j + \lambda \sum_{j=1}^{t} q_j^* + \varepsilon_t,$$

where P_t is the time t trade price, M_1 is the quote midpoint at the beginning of trading day (i.e., 9:00 A.M. EST), Q_j is the signed order imbalance at time j, and Q^*_j is the residual from a fifth-order auto-regression of Q_j, following the specification in Sadka (2006). Expression (12) is estimated for an one-second model with 75 lags of order imbalance (Panel B) and a five-second model with sixty lags of order imbalance (Panel A). For time periods with multiple trades P_t is measured as the last trade price and Q_j is measured as net trade imbalance during the period. The geometric lag expression (12) is estimated by Generalized Method of Moments (GMM), using SAS Proc Model with a Bartlett Kernel set equal to the lag length plus one.

	Observations	alpha (α)	Lambda (λ)	Gamma (γ)	Theta (θ)	R^2
Panel A: Time interval = 5 seconds; Lags = 60						
Front Contract: Full sample	1,086,363	25.643	0.056	0.021	0.959	53.16%
Non-Roll Days	836,963	18.942	0.058	0.020	0.959	52.84%
Roll	48,412	50.860	0.054	0.038	0.986	63.11%
Difference		31.918 ***	-0.004 **	0.018	0.027	
p-value		(0.00)	(0.03)	(0.21)	(0.11)	
Second Contract: Full sample	1,084,194	-8.196	0.084	0.057	0.982	15.47%
Non-Roll Days	835,194	-9.860	0.082	0.048	0.977	16.61%
Roll	48,378	23.505	0.149	0.151	0.993	9.49%
Difference		33.365 ***	0.067 ***	0.104	0.016	
p-value		(0.00)	(0.00)	(0.20)	(0.42)	
Panel B: Time interval = 1 second; Lags = 75						
Front Contract: Full sample	5,261,609	25.84	0.051	0.038	0.976	53.64%
Non-Roll Days	4,047,759	19.180	0.052	0.036	0.975	53.28%
Roll	237,349	53.110	0.050	0.063	0.990	64.35%
Difference		33.930 ***	-0.002 ***	0.027	0.015 *	
p-value		(0.00)	(0.00)	(0.12)	(0.07)	
Second Contract: Full sample	5,184,068	-7.410	0.076	0.070	0.994	16.46%
Non-Roll Days	3,987,888	-8.792	0.075	0.060	0.993	17.44%
Roll	213,335	36.440	0.143	0.182	0.996	9.48%
Difference		45.232 ***	0.069 ***	0.122	0.004	
		(0.00)	(0.00)	(0.18)	(0.77)	

Table 5: Strategic Trading surrounding the USO Roll

Reported in Panel A are patterns associated with twelve strategic trading strategies associated with the USO roll. To be identified as a strategic trader, the absolute value of net change in the (non-ETF) account's inventory to the account's total activity surrounding the roll must be less than 0.25. The "During" period is defined as between 9 A.M. and 5 P.M. EST on the USO roll day, the "Before" period is defined from Midnight on Day -3 (three trading days prior) to 9 A.M. on roll day, and the "After" period is defined from 5 P.M. on roll day to Midnight on Day +3 (three trading days after) relative to the roll day. A strategic trader whose signed position change on roll day moves *against* USO's inventory change is deemed a liquidity provider (Strategies ST1 to ST5) while a strategic trader whose signed position change on roll day moves *with* USO's inventory change is deemed a predatory trader (Strategies ST8 to ST12). Categories ST6 and ST7 correspond to trading patterns with no trading activity on the roll day. Strategic traders are further classified into one of five sub-strategies within liquidity provision (ST1-ST5) and predatory trading (ST8-ST12) based on the account's change in net positions in the Before and After period. Also identified below is the complementary strategy where strategic traders pursue an opposite trading pattern surrounding the USO roll. Panel A reports the direction of USO activity and those for each strategy for expiring (front) contract and next-to-expiring (second) contract on USO roll days.

Panel A: Direction of ETF and Strategic Trading surrounding the USO Roll

Strategy	Trading Pattern (relative to ETF)			Front month			Second month			Complement strategy
	Before	During	After	Before	During	After	Before	During	After	
ETF*				none	sell	none	none	buy	none	
ST 1	against	against	with	buy	buy	sell	sell	sell	buy	ST 12
ST 2	none	against	with	none	buy	sell	none	sell	buy	ST 11
ST 3	with	against	against	sell	buy	buy	buy	sell	sell	ST 10
ST 4	with	against	none	sell	buy	none	buy	sell	none	ST 9
ST 5	with	against	with	sell	buy	sell	buy	sell	buy	ST 8
ST 6	against	none	with	buy	none	sell	sell	none	buy	ST 7
ST 7	with	none	against	sell	none	buy	buy	none	sell	ST 6
ST 8	against	with	against	buy	sell	buy	sell	buy	sell	ST 5
ST 9	against	with	none	buy	sell	none	sell	buy	none	ST 4
ST 10	against	with	with	buy	sell	sell	sell	buy	buy	ST 3
ST 11	none	with	against	none	sell	buy	none	buy	sell	ST 2
ST 12	with	with	against	sell	sell	buy	buy	buy	sell	ST 1

Table 5, Panel B presents regressions coefficients of normalized strategic volume for all days (USO roll and Control days) on an USO roll day indicator variable. The analysis relies on the CFTC dataset. The *strategic volume* is aggregated across all (non-ETF) trading accounts associated with a specific strategy, identified in Panel A, where strategic volume is simply the round trip volume associated with an account surrounding the roll. We define *Normalized strategic volume* as the strategic volume in a strategy less strategic volume in complementary strategy. Such normalization accounts for abnormal trading volume and liquidity associated with a roll day and allows comparison of trading activity across USO roll and non-roll days. We calculate Normalized strategic volume for each strategy on every roll day and every usable non-roll day. A usable non-roll day (Control Day 0) is defined as a day when Days [-3, +3] relative to Control Day 0 does not have any overlap with [-3,+3] relative to USO roll day. The roll-day indicator variable takes the value of one for an USO roll day, and equals zero otherwise.

	Long Window						**Short Window**					
Panel B: Normalized	**ST1**	**ST2**	**ST3**	**ST4**	**ST5**	**ST6**	**ST1**	**ST2**	**ST3**	**ST4**	**ST5**	**ST6**
Front Month Contract												
Intercept	-306	-52	-851	368	3	-244	60	29	10	-84	-25	5
t(Intercept)	-0.86	-0.77	-2.14	4.09	0.01	-1.44	1.70	2.31	0.38	-1.79	-0.51	0.40
Roll_day	-2187	200	3178	219	9	-807	720	-4	-196	104	544	85
t(Roll_day)	-2.06	0.98	2.66	0.81	0.01	-1.60	4.49	-0.07	-1.60	0.49	2.43	1.41
Second Month Contract												
Intercept	-89	30	-396	-79	102	-83	70	54	70	146	173	0
t(Intercept)	-0.42	0.43	-1.52	-0.87	0.59	-0.59	2.35	4.89	2.86	5.53	5.00	-0.06
Roll_day	-1453	179	2028	67	2	56	736	43	-287	-6	13	0
t(Roll_day)	-2.30	0.88	2.60	0.25	0.00	0.13	5.39	0.86	-2.58	-0.05	0.08	0.00

Table 6: Understanding the USO ETF Stock Price Performance.

The Table reports on the performance of various futures benchmarks, based on daily data from January 1990 to December 2013. All data except USO ETF share prices are obtained from the United States Energy Information Agency (EIA). Each mean has been annualized by multiplying by 250. The cost of storage is the futures term slope implied by the settlement prices of the first and second month crude oil futures contracts. The spot price return is the change in the implied (by the nearest futures price and the cost of carry relation) spot price, while the ex-post Spot Premium is the excess of the spot return over the cost of storage. The nearest futures contract return is based on price changes in the nearest-to-expiration contract, for all days including the last day of trading for the expiring contract. The second nearest futures contract return is based on price changes in the second-nearest-to-expiration contract, for all days including the last day of trading for the expiring contract. The Futures "Benchmark Return" series is based on the settlement price changes that track the USO roll. The divergence of benchmark returns from returns based on alternative roll dates provide estimates of the cost of executing trades at USO benchmark prices.

Spot Returns, USO Returns, and Futures Benchmarks

	ETF Period 4/10/06 to 12/31/13		**2000s, pre ETF 1/1/00 to 4/9/06**		**1990s 1/1/90 to 12/31/99**		**Full Sample 1/1/90 to 12/31/13**	
Days	**1946**		**1564**		**2510**		**6020**	
Variable	**Mean (x250)**	**T-stat**	**Mean (x250)**	**T-stat**	**Mean (x250)**	**T-stat**	**Mean (x250)**	**T-stat**
Spot Price Return: S + U	4.74%	0.33	15.11%	0.94	1.18%	0.09	5.95%	0.70
Cost of Storage S	12.38%	22.22	-7.69%	-12.04	-3.63%	-6.46	0.49%	1.39
Expost Spot Premium U	-7.64%	-0.53	22.80%	1.41	4.81%	0.35	5.46%	0.64
Return, Nearest Futures	-5.63%	-0.43	26.02%	1.79	2.41%	0.21	5.95%	0.79
Return, Second Nearest	-5.80%	-0.47	25.37%	1.86	5.24%	0.52	6.90%	1.02
Futures Benchmark Return	-8.79%	-0.70	20.80%	1.49	4.84%	0.45	4.59%	0.64
Nearest - Benchmark	3.16%	1.02	5.22%	2.17	-2.43%	-0.90	1.36%	0.83
Second - Benchmark	2.99%	2.48	4.57%	2.82	0.40%	0.15	2.31%	1.88
USO ETF Return	-8.42%	-0.69						

Figure 1: United States Oil Fund (USO) share price and Front Month NYMEX Crude Oil Price

The figure presents daily USO share prices and front month NYMEX crude oil prices over the period April 12, 2006 to December 31, 2013. The USO share price is obtained from Bloomberg while the NYMEX crude oil price is obtained from the United States Energy Information Agency.

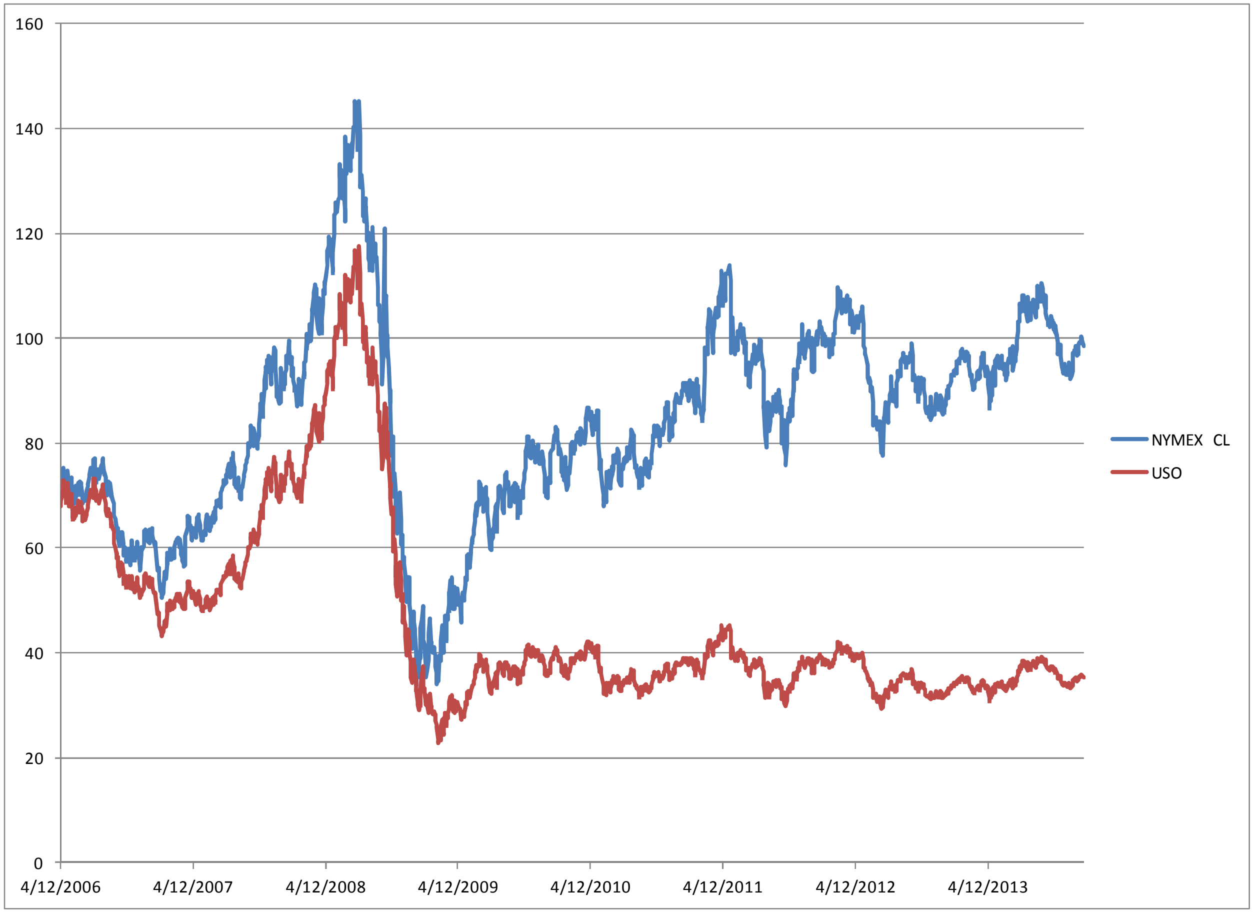


Figure 2: Identifying Front Month contract, Second Month contract, and the USO Roll Strategy

Trading activity in the futures market shifts from nearest-to-expiration (or front) contract to next-nearest-to-expiration (or second) contract a few days before the expiration of the front contract. We refer to the shift in overall trading activity as the Market Roll. USO's roll dates are identified based on their publicly stated investment objective, by which the fund tracks the price of the front NYMEX contract until two weeks before expiration, after which the fund tracks the second contract price. During the March 2008 to February 2009 sample period, USO's roll trades occurred on a single day.

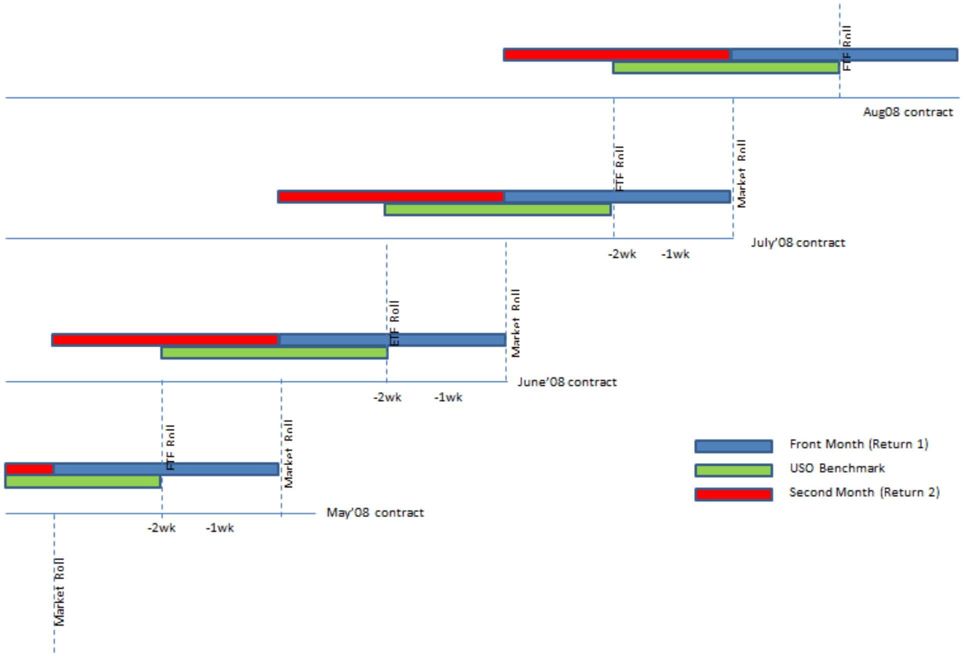
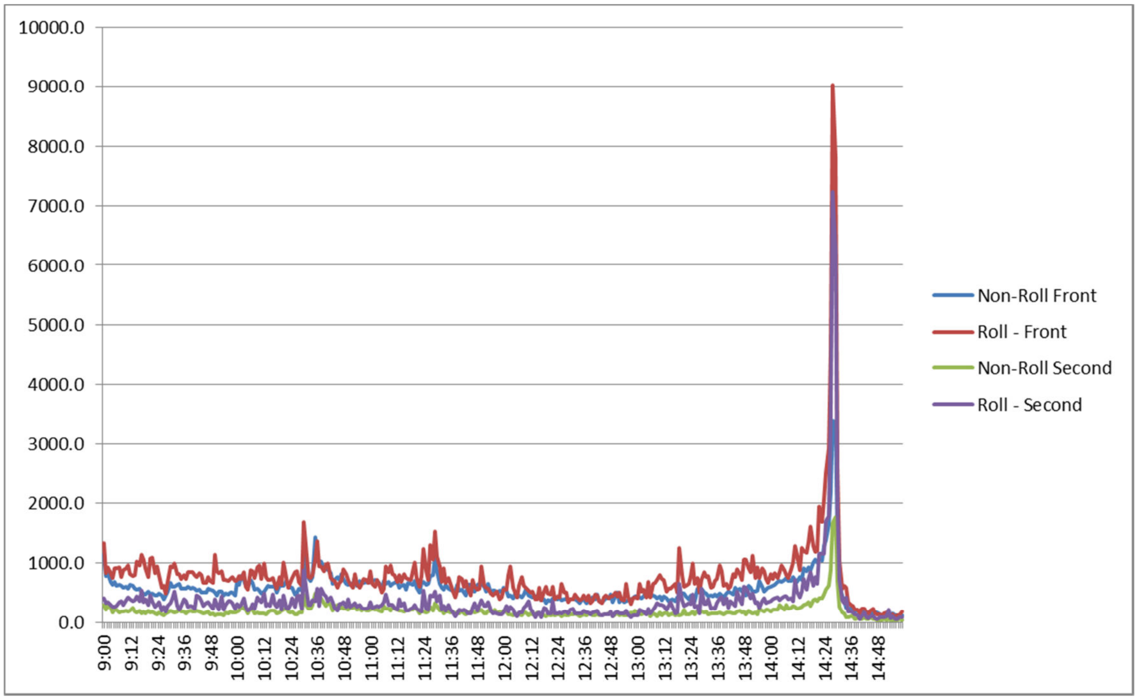


Figure 3: Trading volume and trade imbalance on USO roll and non-roll days.

Reported are intra-day patterns in trading volume and quoted spread on USO roll days and non-roll days in the NYMEX Oil Futures market. We rely on Commodity Futures Trading Commission (CFTC) data for trading volume and Chicago Mercantile Exchange's Datamine database for quoted spread measure. USO's roll dates are identified based on their publicly stated roll strategy. Panel A reports on trading volume on roll days during the period March 1, 2008 to February 28, 2009. Non-roll days are defined as Days [-5,-2] before the roll day. Market quality is calculated each minute of the day and then averaged across USO roll and non-roll days. Trading volume includes all completed trades in NYMEX crude oil futures, including floor and block trades, as well as trades completed on the GLOBEX. Quoted bid-ask spread (in basis points) is the difference between the lowest limit price for unexecuted sell orders and the highest limit price for unexecuted buy orders.

Panel A: Trading Volume on roll and non-roll days



Panel B: Front Month contract – Quoted and Effective spread

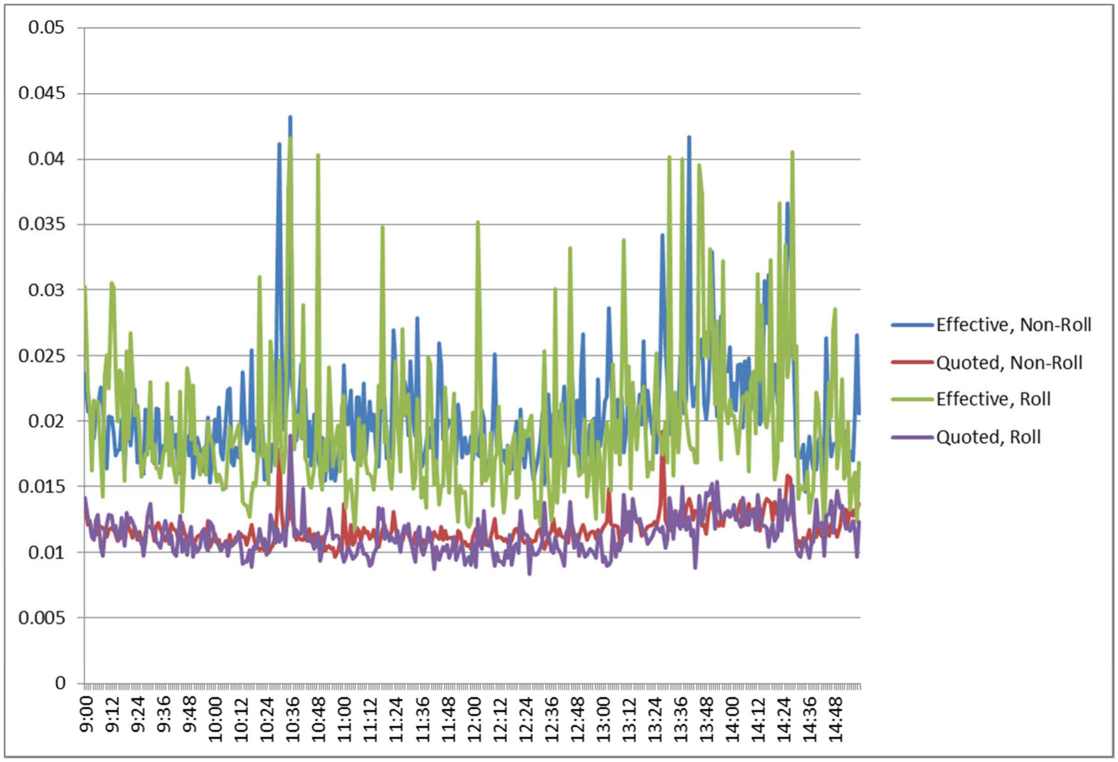


Figure 4: Intraday Limit Order Book depth on USO roll and non-roll days.
Reported are limit order book depth on USO roll days and non-roll days in the NYMEX Oil Futures market. We rely on Chicago Mercantile Exchange's Datamine database on GLOBEX electronic market for the depth measure. USO's roll dates are identified based on their publicly stated roll strategy Non-roll days are defined as days [-5,-2] before the roll day. Market quality is calculated each minute of the day and then averaged across roll and non-roll days. Depth is the total volume of unexecuted sell (ask depth) and buy (bid depth) orders at prices within four ticks of the most competitive prices.

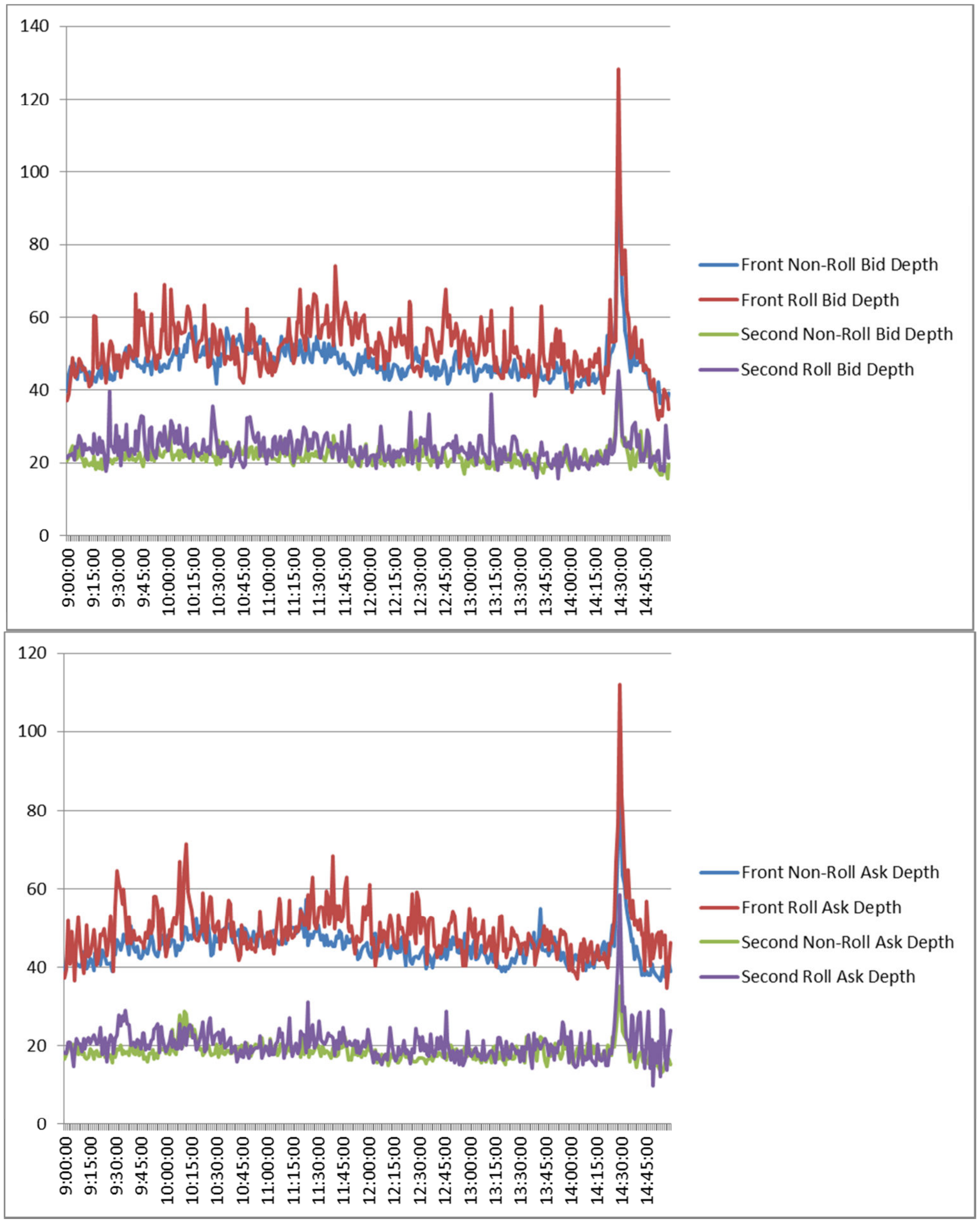
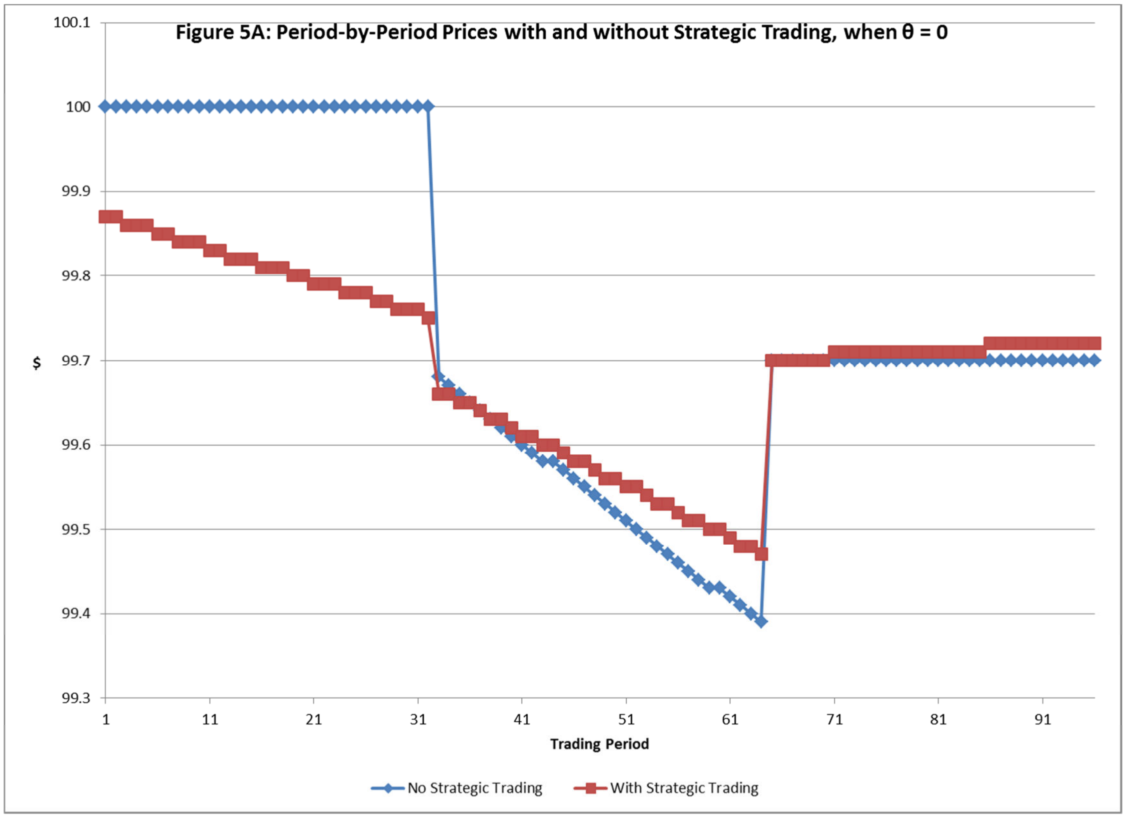


Figure 5: Strategic trading, resiliency and the evolution of price.

Figures 5A and 5B display period-by-period trade prices around a large, pre-announced liquidation. The illustration includes an initial price (V_0) equal to \$100, N = 32 fifteen minute periods within each eight-hour trading day, $Q_L = 20$ units liquidated, temporary price impact, $\gamma = 0.5$, permanent price impact, $\lambda = 0.015$,, for market resiliency parameters, θ, of 0.0 (Figure 5A) and 0.98 (Figure 5B), respectively. Outcomes for intermediate resiliency parameters are generally similar – only when θ approaches 1 are the effects altered. Table 4 illustrates the outcomes of a broader analysis when the strategic trader chooses quantities to maximize profit. The first third of the individual observations pertain to the pre-liquidation day, the second third pertain to the during-liquidation day, and the final third pertain to the post-liquidation day. The small-diamond line illustrates the evolution of price when the strategic trader is absent. The large-square line illustrates the evolution of price when the strategic trader selects quantities to maximize profits, according to expressions (12) and (13).



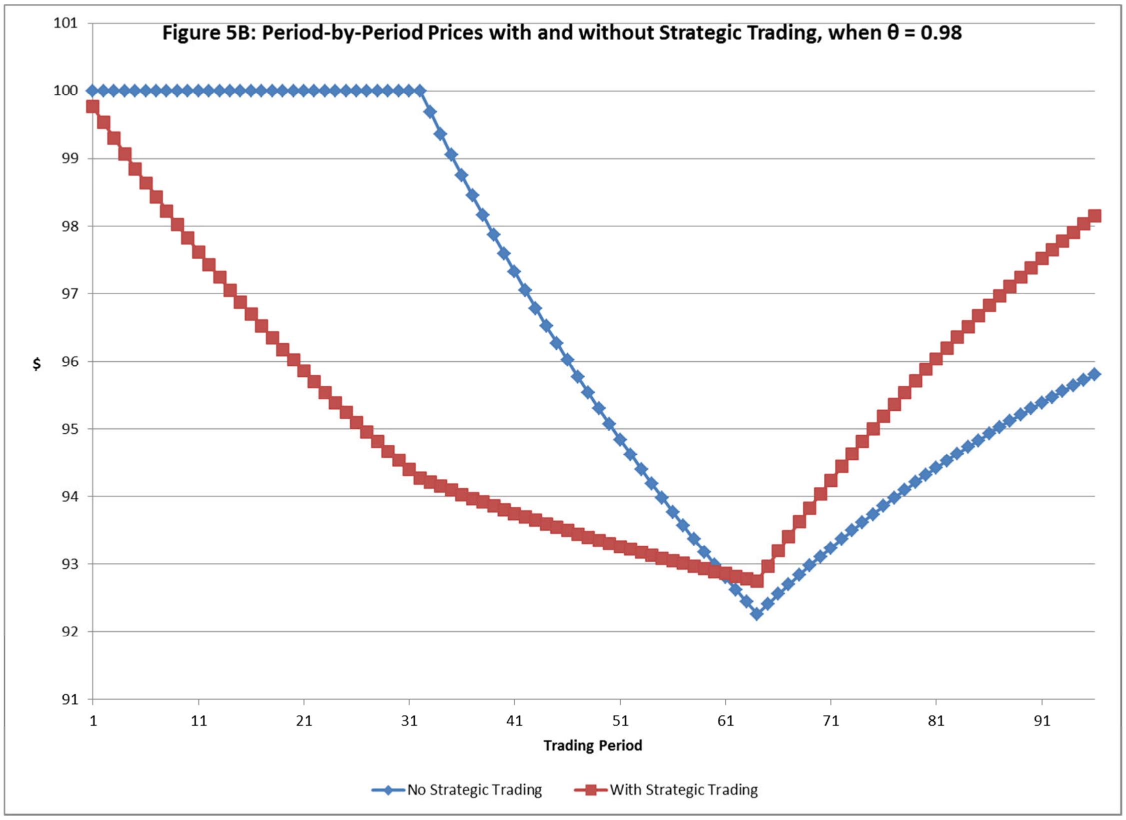


Figure 5B: Period-by-Period Prices with and without Strategic Trading, when θ = 0.98
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61
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81
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Trading Period
No Strategic Trading
With Strategic Trading