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The Negative Pricing of the May 2020 WTI Contract

Adrian Fernandez-Perez*, Ana-Maria Fuertes** and Joëlle Miffre***

Abstract

This paper sheds light on the negative pricing of the May 2020 WTI futures contract (CLK20) on April 20, 2020. The super contango of early 2020, triggered by COVID-19 lockdowns and geopolitical tensions, incentivized cash and carry (C&C) traders to be long CLK20 and short distant contracts, while simultaneously booking storage at Cushing. Our investigation reveals that C&C arbitrage largely contributed to the lack of storage capacity at Cushing in April 2020 and the price crash relates to the reversing trades of many long CLK20 traders without pre-booked storage. Additional aggravating factors included a liquidity crush, staggering margin calls and potential price distortions due to the trade-at-settlement mechanism. The analysis suggests that claims from experts that hold index trackers responsible for the crash are unwarranted: Index trackers did not trigger the negative pricing, nor widen the futures-spot spread by rolling their positions to more distant contracts ahead of maturity.

Keywords: WTI crude oil futures contract; Negative price; Contango; Cash and carry; Index trackers; Disinformation

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The Negative Pricing of the May 2020 WTI Contract

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Executive summary

On April 20, 2020, the day before it was due to mature, the price of the NYMEX WTI crude oil futures contract (known as the May 2020 delivery contract or CLK20) tumbled to -$37.63. This was the first time that a WTI futures contract had experienced a negative price since NYMEX WTI trading began almost 40 years previously. The purpose of this article is to investigate the plausible reasons behind this unprecedented event.

In early 2020, the WTI futures market steered into a super contango due to demand shattered by COVID-19 lockdowns and supply exacerbated by geopolitical tensions. The super contango in turn incentivized cash and carry (C&C) traders to open long positions on CLK20 and short positions in more distant contracts, while simultaneously booking storage at a facility in Cushing (Oklahoma), the delivery hub of NYMEX WTI futures contracts. In this research, two pieces of evidence corroborate the idea of increased participation among C&C arbitrageurs in March and April 2020. First, we note that the futures-spot spread at that time exceeded the cost of financing and carrying the spot asset, and thus C&C arbitrage was profitable. Second, we demonstrate that increases in crude oil inventories at Cushing, in response to the widening of futures-spot spread, were 4.3 times higher in March and April 2020 than had been historically. Both pieces of evidence shed light on the lack of storage capacity at Cushing that prevailed before the negative pricing.

On April 20, 2020, or one day before the maturity of CLK20, the large number of open positions combined with the lack of storage at Cushing contributed to create an unprecedented problem of illiquidity. Long CLK20 traders who had not secured storage at Cushing had to either pay an exorbitant cost for storage, if any free capacity was still available, or close their positions at any price. In the end, they chose to close their positions at negative prices. Among the aggravating factors were i) the staggering margin calls that long traders inexorably had to pay as the price of CLK20 fell and ii) the likely price distortion and market abuse that occurred as a consequence of the trade-at-settlement (TAS) mechanism.

Even within one day after the negative price event, some energy market commentators had blamed index traders for distorting the price of CLK20. The line of reasoning that these market pundits advocated was simply that by rolling their long CLK20 positions to more distant contracts, index traders had triggered the negative pricing of CLK20. We demonstrate the lack of veracity of these claims in reference to the United States Oil fund, the largest WTI crude oil exchange–traded fund, by showing that its flows did not influence either the return or the change in volatility of CLK20. We also show that the rolling of large, long index trader positions on prespecified dates ahead of maturity did not impact the futures-spot spreads in March and April 2020, and thus did not trigger further C&C trades or contribute to the observed negative pricing.

Among the practical implications of this research are lessons to traders with long front-end positions right before maturity, calling them to exert caution in super-contangoed futures markets, since at maturity the long position can suddenly become unfeasible if the asset cannot be physically stored. Our findings thus call for regulators to monitor the long positions of traders close to delivery so that they do not dislocate the natural convergence of the futures and spot prices at maturity. To ensure the integrity of the TAS pricing mechanism, it might be of interest for regulators to limit the netting of speculative TAS positions with speculative outright positions during the contract delivery month.

Keywords: WTI crude oil futures contract; Negative price; Contango; Cash and carry; Index trackers; Disinformation

JEL codes: G13, G14, Q4

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1. INTRODUCTION

This article attempts to shed light on the anomalous pricing of the May 2020 NYMEX West Texas Intermediate (WTI) crude oil futures contract, denoted as CLK20. The price of CLK20 fell dramatically from $18.27 (April 17, 2020) to -$37.63 (April 20, 2020), effectively meaning that sellers paid buyers to take crude oil barrels off their hands.[1] The price then climbed back to $10.01 at maturity (April 21, 2020). It was the first time that a WTI futures contract had experienced a negative price since trading began on March 30, 1983. This article tries to uncover what happened not only in the few weeks preceeding the negative pricing but also on the day that the price turned negative.

The crude oil glut inherited from the 2010s was exacerbated in the early months of 2020 by demand shattered by COVID-19 lockdowns and an oversupply exaccerbated by geopolitical tensions between Russia and Saudi Arabia. Against this background, the WTI futures market steered into a super-contango state; namely, the futures-spot spread became very positive, exceeding its 95th percentile on March 23, 2020. The super-contango that then prevailed incentivized cash and carry (C&C) traders to open long positions on CLK20 and short positions in more distant contracts, while simultaneously booking storage at Cushing, Oklahoma, the delivery hub of WTI futures contracts. As corroborating evidence for the presence of C&C arbitrageurs, we note that from as early as March 5, 2020, the futures-spot spread exceeded the cost of financing and carrying the spot asset, and the profit and loss (P&L) of the C&C arbitrage strategy thus turned positive. To substantiate further the presence of C&C arbitrage, we borrow and extend the research framework of Ederington et al. (2021) and test whether crude oil inventories rose at Cushing in March and April 2020 in response to the widening of the futures-spot spread. We note an increased participation of C&C arbitrageurs around that time: The response of inventories to changes in the futures-spot spread was 4.3 times stronger in March–April 2020 than it typically would be, suggesting that C&C arbitrageurs were then particularly present. We also bring forward evidence that exceptional C&C arbitrage took place outside Cushing, suggesting that, as spare storage capacity started to diminish at Cushing, C&C arbitrageurs considered other hubs as depositories for the crude oil that they had “collected” through their long positions.

[1] One long contract of NYMEX WTI crude oil futures buys 1,000 barrels of oil. Thus, a negative price of -$37.63 per barrel on April 20, 2020 meant that opening a long futures position was then highly beneficial to traders with a storage facility, since the contract holder would receive not only 1,000 barrels of oil at contract expiration but also a $37,630 payment.

Even within one day of the negative price event, some energy market commentators[2] had blamed index traders for distorting the price of CLK20. The line of reasoning advocated by these market pundits was simply that by rolling their long CLK20 positions to more distant contracts, index traders had triggered the negative pricing of CLK20. We substantiate the veracity of this claim—or lack thereof—in two directions. First, as a direct test of the price impact of long index trackers, and in reference to the United States Oil fund (USO), the largest WTI crude oil exchange–traded fund, we investigate whether its flows influenced either the return or the change in the volatility of CLK20. Second, as an indirect test of the price impact of index traders, we examine whether the prespecified rolling of long index positions ahead of maturity impacted futures-spot spreads in March and April 2020, thereby triggering further C&C trades and indirectly contributing to the observed negative pricing. Both tests conclude that there was an absence of price impact and index traders cannot thus be made responsible for disrupting the price of CLK20.

On April 20, 2020, or one day before maturity, a large number of open positions combined with the lack of storage at Cushing created an unprecedented problem of illiquidity. Long CLK20 traders who had not secured storage at Cushing either had to pay an exorbitant cost for storage, if any spare capacity was still available, or close their positions at any price. In the end, most of them chose to close their positions at negative prices. As Nagy and Merton (2020) put it, WTI crude oil became like "toxic waste or even garbage" to long CLK20 traders without prebooked storage on April 20, 2020. In effect, long traders cannot just dump crude in a lake or ocean to dispose of it; for that reason, they deemed *paying* up to $37.63 per WTI crude oil barrel *sold* to be a lesser loss than taking physical delivery. Aggravating factors included i) the staggering margin calls that long traders inexorably had to pay as the price of CLK20 fell and ii) the likely price distortion that occurred as a consequence of the trading-at-settlement (TAS) mechanism. Under that mechanism, it became profitable to buy CLK20 at TAS price during the April 20, 2020 trading day and simultaneouly sell it outright so as to push the TAS price down, offsetting both positions at settlement. This only served to aggravate the price fall.

Our findings speak to the empirical literature on the theory of storage (Kaldor, 1939; Working, 1949; Brennan, 1958)[3] by bringing indirect evidence that the law of one price implied by the cost-of-carry model does not hold in

[2] See, for instance, https://www.wsj.com/articles/the-fund-that-ate-the-oil-market-11587489608 and https://www.forbes.com/sites/vineerbhansali/2020/04/21/negative-price-of-oil-is-telling-us-that-bigger-problems-are-afoot/#5536ed163a5a

[3] Geman and Ohana (2009), Symeonidis et al. (2012), Geman and Smith (2013), Gorton et al. (2013), Alquist et al. (2020), and Ahmadi et al. (2020) confirmed empirically for different commodity markets that low (high) inventory levels are associated with forward curves in backwardation (contango). Using intraday data, Alquist et al. (2020) showed that news of higher-than-expected (lower-than-expected) U.S. crude oil inventories lead to very quick decreases (increases) in the front futures contract price, even within minutes of the announcement.

the presence of storage constraints. In so doing, it complements the analysis of Ederington et al. (2021) by focusing on the anomalous negative pricing of CLK20, and by showing that limits in the availability of storage (i.e., reaching the nightmare scenario of exhausted storage) can drive futures prices into negative territory. Practical implications from this research include lessons to traders with long front-end positions (irrespective of whether they engage in C&C trades) right before maturity, calling them to exert caution in super-contangoed futures markets, since at maturity, the long position can suddenly become unfeasible if the asset cannot be physically stored. Likewise, traders not seeking to take physical delivery (e.g., long index trackers) need to exert caution in rolling their long positions sufficiently ahead of maturity to avoid being caught in such liquidity freeze-outs in the future. Our findings thus call for regulators to monitor the long positions of traders close to delivery so that they do not dislocate the natural convergence of futures and spot prices at maturity. To prevent price distortion and market abuse through the TAS mechanism, it might also be of interest for regulators to limit the netting of speculative TAS positions with speculative outright positions during the contract delivery month. This would ensure the integrity of the TAS pricing mechanism.

Our findings also speak to the literature on the financialization of energy futures markets by showing that index traders, such as USO, did not drive the price of CLK20 away from its fundamental value nor distort the futures-spot spread while rolling their positions ahead of maturity (see, e.g., Till, 2009; Büyükşahin and Harris, 2011; Irwin and Sanders, 2012; Fattouh et al., 2013; Hamilton and Wu, 2015; Brunetti et al., 2016). This suggests that calls for the regulation of long index trackers might be, at this stage, premature. Further regulation could, in fact, be detrimental, as it may discourage index trackers, who are important providers of risk-absorption and liquidity, from trading crude oil futures.

The article unfolds as follows. Section 2 describes the data. Section 3 briefly presents the macroeconomic and political environment of early 2020 that led to a super contango. Sections 4 through 6 analyze the positions of C&C arbitrageurs (Section 4), index trackers (Section 5), and speculators and hedgers (Section 6) and test whether the long CLK20 positions of these traders influenced inventory levels and price formation in the days preceeding the crash. Section 7 explains the dramatic price swing observed in April 20, 2020, and Section 8 concludes.

2. DATA

2.1 Futures Prices

Our analysis relies on the daily settlement prices of all 446 NYMEX WTI crude oil futures that were traded over the period from March 30, 1983 to June 29, 2020, as provided by *Refinitiv Datastream*. These prices are used to measure the returns of various contracts using the formula $(F_{t,T} - F_{t-1,T})/|F_{t-1,T}|$, where $F_{t,T}$ is the time t settlement price of a contract that matures at time T. The use of absolute prices in the return definition is dictated by the negative price observed on April 20, 2020. For comparison with the price evolution of the WTI contracts, we also obtained the daily settlement prices of front- and second-nearest maturity futures contracts on Brent crude oil over the available period from December 12, 1988 to June 29, 2020.

To demonstrate the lack of liquidity of CLK20 in its last two days of trading, we downloaded from *Refinitiv Tick History* intraday best bid, best ask, and transaction prices at a one-minute frequency for CLK20 and its two adjacent WTI contracts (with April 2020 and June 2020 maturities) over their last two days of trading.[4] As another proxy for storage costs, we adopt the prices of ICE Permian WTI storage futures contracts which give the holder the right to store 1,000 barrels of Permian WTI crude oil at Magellan's terminal in East Houston, Texas. The data are daily front-end settlement prices from the inception of this futures market on March 4, 2019 until June 29, 2020 that we obtain from *Refinitiv Tick History.*

2.2 Control Variables

Throughout our analysis, we investigate whether a certain group of traders impacted inventory levels or the price and volatility of CLK20. The analysis is implemented after accounting for various oil market-specific and macroeconomic factors that have been shown in the literature to explain inventory levels and/or price commodity futures contracts (e.g., Singleton, 2014; Algieri and Leccadito, 2019; Wimmer et al., 2021). The factors that we consider as control variables are: i) the futures-spot spread of Erb and Harvey (2006) and Gorton and Rouwenhorst (2006) defined as $F_{t,T_2} - S_t = F_{t,T_2} - F_{t,T_1}$, with $T_1 < T_2$ and T_1 (T_2) the maturity of the front-end (second-end) futures contract; ii) the momentum signal of Miffre and Rallis (2007) measured as the 50-day averaged returns of front-end contracts; iii) the basis-momentum signal of Boons and Prado (2019) defined as the difference between the 50-day averaged returns of the front- and second-nearest contracts; iv) the relative basis signal of Gu et al. (2020) measured as $F_{t,T_1} - 2F_{t,T_2} + F_{t,T_3}$, with $T_1 < T_2 < T_3$, all of which are commodity-specific factors.[5] In addition, we consider overall macroeconomic activity indicators such as v) the economic policy uncertainty (EPU)

[4] WTI futures contracts trade almost 24 hours from Sunday to Friday, 6:00 p.m. to 5:00 p.m. Eastern Time (E.T.). There is a 60-minute break each day beginning at 5:00 p.m. E.T.

[5] The futures-spot spread at time *t* measures the slope of the term structure of commodity futures prices with negative values signifying a backwardated market with scarce inventory levels. The momentum signal models price continuation. The basis-momentum signal captures imbalances in supply and demand of futures contracts during episodes of high volatility and illiquidity. The relative basis signal measures the convexity or concavity of the price curve, whereby a concave futures curve indicates a low convenience yield and abundant commodity, and thus contango. Higher values of the futures-spot spread and lower values of the momentum, basis-momentum, and relative basis signals predict lower excess returns in the near future.

index of Baker et al. (2016); vi) the Aruoba et al. (2009) index designed to track real business conditions at high frequency (known also as ADS for Aruoba–Diebold–Scotti); and vii) the Chicago Board Options Exchange's volatility index (VIX) used as a proxy for market sentiment (see, e.g., Baker and Wurgler, 2007; Da et al., 2015; or Gao and Süss, 2015 for an analysis of sentiment in commodity markets).

2.3 Required Additional Data

Our empirical analysis is also based on crude oil weekly inventories and working storage capacities at Cushing, which is the delivery hub of NYMEX WTI crude oil futures contracts, and at all the Petroleum Administration for Defense Districts (PADDs) outside Cushing. The data were obtained from the Energy Information Administration (EIA) website and exclude strategic petroleum reserves. Our investigation of the price impact of long index trackers employs the open interest at day-close of USO on all the NYMEX WTI crude oil it traded. We also downloaded the weekly long and short positions of large non-commercial traders (speculators) on WTI contracts, as reported by the U.S. Commodity Futures Trading Commission (CFTC) on the Commitments of Traders (CoT) report from the CFTC's website. The start date of these datasets depends on the data providers (April 9, 2004 for the EIA inventories, October 24, 2008 for USO's open interest, and October 6, 1992 for CoT), and the end date is late June 2020 in all settings. Finally, we obtained monthly worldwide crude oil production from the EIA website and monthly worldwide and U.S. crude oil and liquid fuels consumption from *Refinitiv Datastream*.

3. THE 2020 MACROECONOMIC AND POLITICAL ENVIRONMENTS

The world oil market experienced an ongoing oversupply (or glut) in the decade prior to the events in this study. Among the various factors contributing to it, one that was prominent is the U.S. shale oil revolution that started in 2011 (Kilian, 2016), while other factors include i) a steadily falling worldwide demand for crude oil due to, e.g., the slowdown of the Chinese economy, ii) the end of U.S. quantitative easing, and iii) environmental policies that promoted an increasing share of energy consumption away from fossil fuels (e.g., the Paris Agreement of 2015). In 2019, concerns about oil demand centered on the U.S.–China trade dispute, thorny Brexit negotiations, and slower-than-expected economic growth by India.

The COVID-19 outbreak turned the oil glut of the 2010s into a tsunami of oversupply and shifted the market towards contango. On January 30, 2020, the World Health Organization (WHO) officially declared the COVID-19 outbreak a public health emergency of international concern; on March 11, 2020, it was declared a pandemic. Attempts to curb the rapid contagion led to worldwide economic lockdowns and the closure of thousands of restaurants and other businesses, reduced or ceased production at factories, fewer public transport services, less driving, and a sharp reduction in air travel. As a result, consumption of crude oil and liquid fuels dropped suddenly by 18.28% worldwide (19.63% in the U.S.) from March 2020 to April 2020. The corresponding figures for the period from April 2019 to April 2020 are equally shocking (-25.48% worldwide and -27.74% and for the U.S.).

In the meantime, geopolitical tensions between Russia and Saudi Arabia worsened the contango. For example, in March 6, 2020, Russia rejected a call from OPEC members to cut production, triggering a $10 fall in crude oil prices on March 9, 2020 (or a drop by 28.22% in one trading day). In retaliation, Saudi Arabia announced an increase in its production, which Russia then matched, serving to worsen the price fall. On April 9, 2020, and following political pressure by the U.S., OPEC and non-OPEC countries finally agreed to massively cut production by 9.7 million barrels per day (or by 11.8% of world production on March 2020) from May 1, 2020. However, these cuts were considered "too little too late" in light of the COVID-19 demand shock, and prices kept on dropping as a result. Figure 1, Panel A shows the timeline of these events alongside the CLK20 price.

[Insert Figure 1 around here]

Figure 1, Panel B plots the daily futures-spot spreads for WTI and Brent crude oil from January 1, 2019 to June 29, 2020. There was a switch from a negative spread (backwardation) to a persistently positive spread (contango) on January 14, 2020 for WTI and on March 4, 2020 for Brent. The early contango initially driven by the geopolitical and economic conditions mentioned above turned into a super-contango in late March 2020. The WTI spread then rose above the 95th percentile of its distribution over the entire available period from March 30, 1983 to June 29, 2020, eventually reaching an astonishing $58.06 on April 20, 2020. Brent also entered a super-contango state relative to its historical spread, but its price did not become negative. These observations indirectly suggest that crude oil supply and demand imbalances, and the associated super-contango of futures prices *per se*, did not trigger the WTI futures price collapse on April 20, 2020, since otherwise, a negative price should also have been observed to some extent for Brent futures. Thus, something else linked to the Cushing storage hub, and the CLK20 contract in particular, must have played a key role.

4. CASH AND CARRY ARBITRAGE

In the context of a contango, C&C arbitrageurs[6] have an incentive to take long positions in the spot asset (or in front-maturity contracts) and short positions in distant-maturity contracts. As long as the futures-spot spread is larger than the cost of funding and carrying the physical commodity, the arbitrage trade is profitable. We argue that the super-contango that prevailed as of March 2020 in the WTI futures market incentivized C&C traders to open long positions on CLK20 and short positions in more distant contracts, while simultaneously booking storage at Cushing.

To corroborate this assertion, we measure the P&L of C&C trades over the period from January 1, 2020 to June 29, 2020 as the difference between the futures-spot spreads and the monthly cost of financing and carrying the spot asset, noting that market participants are likely to engage in C&C arbitrage when the P&L of this strategy is positive. We ignore the convenience yield because it is negligible in deeply contangoed markets. To calculate the cost of financing the physical asset we adopt the 3-month U.S. Treasury bill rate as funding rate, and consider two proxies for the cost of carrying the spot asset (since there is no data available on Cushing storage costs). The first proxy is set to 0.74% of the spot price (or front-end WTI crude oil futures price), which is an estimate of the storage price in contango markets (Stancu et al., 2021). As another proxy we consider the settlement price of front-end ICE Permian WTI storage futures contracts. Figure 2, Panel A plots the resulting front-end Permian WTI storage futures continuous settlement prices as obtained since inception on March 4, 2019. It is clear from this graph that the cost of storage substantially rose on April 7, 2020 to $3.71 per barrel (note the full sample average is merely $0.28 per barrel), suggesting that from that date onwards, market participants were aware of the scarcity of spare storage capacity. Figure 2, Panel B plots the P&L of the C&C strategy, showing that the strategy turned profitable on March 9, 2020 and March 5, 2020, respectively, based on these two estimates of storage cost. Taking the Permian WTI storage futures as the storage cost proxy, it appears that the C&C P&L still remained positive at $1.35 per barrel on April 7, 2020, suggesting that even in an environment of scarce storage capacity, market participants still had incentive to engage in C&C arbitrage.

[Insert Figure 2 around here]

This analysis provides *prima facie* evidence that C&C arbitrageurs were remarkably present in the WTI futures market ahead of the negative pricing. We can further support this assertion empirically by testing whether crude oil inventories rose in March and April 2020 in response to the widening of the futures-spot spread. To do that, we

[6] C&C traders are big financial institutions with the ability to borrow capital (e.g., investment banks, hedge funds, and proprietary trading houses) and oil companies that lease storage capacity at Cushing. For further discussion, see Davis (2007) and Ederington et al. (2020).

borrow the research framework of Ederington et al. (2021) and measure the impact of spread changes on inventory changes over the critical March–April 2020 period. Specifically, we estimate the following regression:

$$\Delta Inv_t = b_0 + \sum_{j=0}^{4} b_{1,j}\Delta SP_{t-j} + \sum_{j=0}^{4} b_{2,j}\Delta SP_{t-j}D_t + \sum_{k=1}^{K} \theta_k Ctrl_{k,t} + \varepsilon_t, \quad (1)$$

where Inv_t is the weekly crude oil inventory at Cushing at week *t*, $SP_t = F_{t,T} - S_t$ is the futures-spot spread at week *t*, $F_{t,T}$ is the week *t* futures price of a contract that matures at time *T*, S_t is the spot price (or the price of the front contract), $Ctrl_t$ are control variables other than the futures-spot spread as mentioned in Section 2.2 (i.e., momentum, basis-momentum, relative basis, EPU, ADS, and VIX), ε_t is an error term, and D_t is a C&C dummy variable that takes the value of 1 in the weeks from March 6, 2020 to April 17, 2020 (i.e., when C&C was profitable) and 0 otherwise.[7] The data used to estimate Equation (1) start on April 9, 2004, measured each Friday as dictated by the availability of oil inventory data on the EIA website, and end on June 29, 2020.

The results are reported in Table 1, Panel A. We infer that $b_{1,j} > 0$ for $j = 0, \ldots, 4$, confirming the predictive power of changes in futures-spot spreads over the changes in crude oil stocks at Cushing during the whole sample period (Ederington et al., 2021). We also infer that $b_{2,j} > 0$ for $j = 1, \ldots, 4$, although with statistical significance only for $j = \{1, 4\}$, and the joint hypothesis that $b_{2,j} = 0$ for all $j = 0, \ldots, 4$ is strongly rejected. This evidence suggests that from March 6, 2020 to April 17, 2020, crude oil inventories rose at Cushing in response to changes in futures spreads substantially more than they would typically do. For example, a one standard deviation rise in the futures-spot spread (i.e., a rise of \$0.52) would lead on average to a rise in Cushing inventory levels of $0.52 \cdot \left(\sum_{j=0}^{4} \hat{b}_{1,j}\right)/5 = 290$ thousand barrels per week. This increase is substantial and represents around 24% of the standard deviation in the weekly crude oil inventory changes at Cushing. In March–April 2020, a one standard deviation rise in the futures-spot spread led to a rise in Cushing inventory levels by $0.52 \cdot \left(\sum_{j=0}^{4}\left(\hat{b}_{1,j} + \hat{b}_{2,j}\right)\right)/5 =$ 1.248 million barrels per week. This corresponds to more than one standard deviation in the weekly crude oil inventory changes at Cushing, or more than a fourfold (precisely 4.3) increase in the typical response of Cushing inventories to changes in the futures-spot spread – this suggests that as contango deepened, C&C arbitrage intensified at Cushing. Figure 3 plots the storage capacity utilization rate at Cushing and that of all other hubs but Cushing from January 17, 2020 to June 26, 2020 and confirms that storage utilization sharply rose in March and April 2020. Specifically, the storage capacity utilization rate at Cushing was 47.05% in March 6, 2020 and rose to

[7] The small number of weekly observations available for the estimation of $b_{2,j}$ forces us to limit the lag order employed in Equation (1) to 4, unlike Ederington et al. (2020).

75.86% in April 17, 2020. Note that the vast majority of the storage space at Cushing on April 17, 2020 had already been committed (CFTC's Interim Staff Report, November 2020).

[Insert Table 1 and Figure 3 around here]

Following Ederington et al. (2021), we implement a similar analysis using inventory data at hubs other than Cushing. The results reported in Table 1, Panel B indicate a failure to reject the null hypothesis $b_{1,j} = 0$ for all $j = 0, \ldots, 4$. This confirms that PADDs other than Cushing do not serve as arbitrage hubs, a result previously reported in Ederington et al. (2021). Interestingly, the null hypothesis $b_{2,j} = 0$ for all $j = 0, \ldots, 4$ is rejected, an indication that exceptional C&C arbitrage took place outside Cushing over the period from March 6, 2020 to April 17, 2020. This suggests that as spare storage capacity started to diminish at Cushing, C&C arbitrageurs considered other hubs as depositories for the crude oil they had "collected" through their long positions.[8] However, the volume of these arbitrage trades was rather small in comparison to that associated with the Cushing facility as Figure 3 clearly demonstrates. The rise in inventories outside Cushing over the period from March 6, 2020 to April 17, 2020 is quite mild (at 6.17%) relative to that observed at Cushing (at 28.81%).

5. INDEX TRADING

Some energy market commentators blamed the largest WTI crude oil exchange–traded fund, the United States Oil fund (USO),[9] for distorting the price of CLK20. The line of reasoning these market pundits advocated was simply that by rolling long CLK20 positions to more distant contracts, USO would trigger the negative pricing of CLK20. More generally speaking, we investigate the potential role of long index trackers in two directions. First, as a direct test of their price impact, we investigate whether USO flows influenced the return and the change in the volatility of CLK20 and those of all NYMEX WTI contracts it traded over a period from October 24, 2008 to June 29, 2020. Second, as an indirect test of the price impact of long index trackers, we examine whether the rolling of positions of long index trackers on prespecified trading days before their maturities impacted the futures-spot spreads, thereby triggering further C&C trades and indirectly contributing to the observed negative pricing.

[8] C&C arbitrage is not intrinsically linked to Cushing (or WTI-grade oil) since it is possible to use other short forward contracts calling for delivery at another location (or non-WTI-grade oil) but these incur transportation costs and basis risk (Ederington et al., 2021).

[9] USO is the largest crude oil exchange–traded fund. Like any other index tracker, USO does not hold oil inventories, which would entail potentially large storage and insurance costs, but instead holds long positions in front-end maturity contracts and rolls them to more distant contracts several days before the front-end contracts mature. In May 2020, USO started rolling over a 10-day period, whereas it had previously rolled over a 4-day period.

5.1. Do USO Flows Impact Changes in the Price and Volatility of WTI Crude Oil?

Figure 4, Panel A plots the daily open interest of USO on CLK20 against the daily settlement prices of the contract. The data reveals that at day-close on April 13, 2020 (already seven days before the price crash of CLK20), USO did not hold any CLK20 contract. This represents *prima facie* evidence that USO trading is unlikely to have triggered the anomalous negative pricing. Nevertheless, through the rolling of its long CLK20 positions, it could have prompted a drop in the price of CLK20 a few days before the crash, indirectly aggravating the situation.

[Insert Figure 4 around here]

To fully answer the question as to whether USO distorted the WTI crude oil market, we pool the daily excess returns of the WTI futures contracts that USO traded over the period from October 24, 2008 to June 29, 2020 and proceed likewise for the daily changes in their open interest. The pooled time-series, denoted r_t and ΔOI_t, respectively, have length $T = \sum_{n=1}^{N} T_n = 3{,}767$, where T_n is the number of days during which USO held long positions on the *n*th contract and N is the total number of contracts that USO held ($N = 148$).

We then estimate the following (unbalanced) panel regression for $t = 1, \dots, T$:

$$r_t = \alpha_n + \alpha_m + \sum_{i=1}^{I} \left(\beta_i + \beta_{D,i} D_t\right) \Delta OI_{t-i} + \sum_{j=1}^{J} \left(\delta_j + \delta_{D,j} D_t\right) r_{t-j} + \sum_{k=1}^{K} \gamma_k Ctrl_{k,t-1} + \varepsilon_t, \qquad (2)$$

where r_t is the day *t* WTI futures return, ΔOI_t is the day *t* change in USO's open interest on the corresponding[10] contract, α_n $(n = 1, \dots, N)$ are individual fixed effects that account for unobserved heterogeneity across contracts, α_m are month-of-the-year time effects that account for seasonality in crude oil markets, D_t is a dummy equal to 1 on days when USO was long on CLK20 (from March 6, 2020 to April 13, 2020) and 0 otherwise, $Ctrl_{k,t-1}$ are a set of *k* controls as explained in Section 2.2 (as these variables are considered as predictors of futures returns, we use their first lag), and ε_t is an error term. The parameters $\beta_{D,i}$ capture the effects of USO trading on CLK20 prices over and above the effect of USO trading on all other WTI contracts where the latter is modelled by β_i. Similarly, $\delta_{D,j}$ captures the incremental influence of lagged CLK20 returns over and above the effect of all other contract lagged returns as captured by δ_j.

We also test whether changes in USO's positions in WTI futures contracts predict changes in the volatility of WTI futures returns. For this purpose, we fit a GARCH (1, 1) model to the daily WTI excess returns of any given

[10] The excess returns observed at time *t* and the change in USO's open interest measured at time $t - i$ pertain to the same contract. We proceed similarly as regards Equation (3).

contract traded by USO using all the price data available and select the conditional volatility observations that match the dates during which USO traded that contract. We repeat this process for all the contracts that USO traded which enable a pooled series of conditional annualized volatilities, h_t. We then estimate the following (unbalanced) panel regression model:

$$\Delta h_t = \alpha_n + \alpha_m + \sum_{i=1}^{I}(\beta_i + \beta_{D,i}D_t)\Delta OI_{t-i} + \sum_{j=1}^{J}(\delta_j + \delta_{D,j}D_t)\Delta h_{t-j} + \sum_{k=1}^{K}\gamma_k Ctrl_{k,t-1} + \varepsilon_t, \quad (3)$$

where Δh_t is the day *t* pooled annualized volatility change, the other variables are as described above for Equation (2), and ε_t is an error term.

The commodity futures markets literature takes the absence of predictive correlation between ΔOI_{t-i} and the dependent variables of Equations (2) and (3) (β_i are jointly equal to 0) as an indication that the so-called financialization of commodity futures markets was not harmful to price formation (Büyükşahin and Harris, 2011; Irwin and Sanders, 2012; Hamilton and Wu, 2015; Brunetti et al., 2016, to name only a few papers). Building on this literature, we analyze the predictive power of USO trading over the price and volatility changes of WTI contracts by testing the null hypothesis $H_{01}: \beta_1 = \cdots = \beta_I = 0$. We also test the hypothesis $H_{02}: \beta_{D,1} = \cdots = \beta_{D,I} = 0$, as this test allows us to assess whether USO's flows impacted the price and volatility of CLK20 more than it impacted the behaviour of any other WTI-traded contracts.

The unit root tests of Levin et al. (2002) and Im et al. (2003) show that the panel series of WTI excess returns, WTI volatility changes, and changes in USO's open interest are stationary; unreported results (to preserve space) are available from the authors. The appropriate lag length *I* for the change in open interest and *J* for the return (change in volatility) are identified via a data-based search procedure.[11] The fixed effects regressions are estimated via OLS. We study the behavior of the residuals of Equations (2) and (3). Specifically, we apply the modified Wald test for groupwise heteroscedasticity in the error term of Equations (2) and (3) (the null hypothesis is groupwise homoscedasticity), the Wooldridge test for serial correlation (the null hypothesis is that the residuals are serially uncorrelated), and finally, the pairwise contemporaneous correlations across residuals (the null hypothesis is that the residuals are cross-sectional uncorrelated).[12] These tests suggest that the residuals in

[11] We set *I* and *J* at a maximum of 5 days and select the lag orders that minimize the BIC criterion and make the residuals serially uncorrelated (Enders, 1995; Büyükşahin and Harris, 2011; Irwin and Sanders, 2012). This resulted in $I = 2$ and $J = 2$ for the return equation and in $I = 4$ and $J = 5$ for the change in volatility regression.

[12] USO typically holds positions on one or two contracts in a given day. We test for the presence of cross-sectional dependence in the error terms of Equations (2) and (3) by measuring the contemporaneous correlation across residual pairs. To do so, we pool all the pairs of residuals pertaining to same-date WTI contracts, and then estimate the Pearson correlation coefficient.

Equations (2) and (3) are groupwise heteroscedastic, serially uncorrelated, and cross-correlated. Therefore, the inferences in our regressions are based on the White robust standard errors (period clustered), which is robust to contemporaneous correlation and heteroscedasticity across contracts. The estimation window is dictated by the availability of daily data on USO's positions and covers the period from October 24, 2008 to June 29, 2020.

For *prima facie* evidence against the hypothesis that USO had a price impact on WTI futures, we measure the contemporaneous correlations between USO's changes in open interest and WTI excess returns (changes in volatility). The results indicate a lack of correlation between the series. Specifically, the correlation between the changes in USO's open interest and WTI excess returns (changes in volatility) is an insignificant 1.5% (-0.3%). More formally, Table 2 summarizes the estimations of Equations (2) and (3), focusing on β_i and $\beta_{i,D}$, the coefficients of interest. Panel A centers on the predictive power of USO's flows over WTI returns in general and over CLK20 returns in particular. Panel B proceeds likewise but questions the capacity of USO to alter the volatility of the contracts it traded. The joint hypotheses $H_{01}: \beta_1 = \cdots = \beta_I = 0$ and $H_{02}: \beta_{D,1} = \cdots = \beta_{D,I} = 0$ cannot be rejected by the Wald test in either panel. Over the period from October 24, 2008 to June 29, 2020, the changes in USO's positions have no predictive power over the changes in the price or volatility of the WTI futures contracts it traded, be they CLK20 or other contracts. Overall, the evidence suggests that USO did not distort the NYMEX WTI crude oil market; that is, it did not influence the pricing of CLK20 in the period that preceeded the crash.

[Insert Table 2 around here]

5.2 Does the Rolling of Long Index Trackers' Positions Alter Futures-Spot Spreads?

Long index trackers hold futures contracts up to some pre-specified dates and then shift their asset allocation to more distant (typically second) contracts. It is intuitive, therefore, to hypothesize that the selling pressure of front contracts and buying pressure of second nearest contracts could have widened the futures-spot spread in April 2020, making the WTI market more contangoed than it would have been otherwise. The hypothetical deepening of the contango triggered by indexers could in turn have led to an increase in C&C trades, suggesting that, indirectly, indexers contributed to the lack of storage at Cushing and to the observed negative pricing.

Our analysis centers on the Standard & Poor's Goldman Sachs Commodity Index (S&P GSCI), the Dow Jones-UBS Commodity Index (DJ-UBSCI), and USO, which have pre-specified days over which they roll their WTI positions. The rolling takes place from the 5th to the 9th trading day of maturity months for the S&P GSCI, from the 6th to the 10th trading day of maturity months for DJ-UBSCI, and it varies across contracts for USO, as specified by USCF and summarized in Figure 4, Panel B. We estimate the following regression:

$$r_{D,t^*} - r_{F,t^*} = a_0 + a_1 D_{t^*} + \sum_{k=1}^{K} \theta_k Ctrl_{k,t^*-1} + \varepsilon_{t^*}, \quad (4)$$

where r_{D,t^*} (r_{F,t^*}) denotes the excess return of the distant (front) contract that is bought (sold), t^* are the S&P GSCI, DJ-UBSCI, and USO rolling days over a common sample from October 24, 2008 to June 29, 2020, D_{t^*} is a dummy equal to 1 for CLK20 (i.e., when this contract is used to calculate either r_{D,t^*} or r_{F,t^*}) and 0 otherwise, and ε_{t^*} is an error term. The control variables, as with all other specifications, are lagged values of the futures spread, momentum, basis-momentum, relative basis, EPU, ADS, and VIX.

We conduct two tests. The first one for the null hypothesis $H_{01}: a_0 = 0$ is aimed to ascertain whether index trackers, after controlling for the fundamentals of WTI futures pricing, impact futures-spot spreads in general (namely, over all WTI crude oil contracts held over the sample period October 24, 2008 to June 29, 2020). The second test for $H_{02}: a_1 = 0$ is aimed to assess whether the widening of the futures-spot spread measured in relation to CLK20 was stronger than typical widening observed over the whole cross-section of WTI futures contracts.

The results presented in Table 3 suggest, uniformly across all three major index trackers, that their rolling of positions has no impact on futures-spot spreads in general (aligned with the evidence in Hamilton and Wu, 2015) nor, in particular, for the critical CLK20 contract. With this evidence at hand, we assert that index trackers did not widen the futures-spot spread in April 2020 and thus, they did not induce the-then very intense C&C trading activity.

[Insert Table 3 around here]

6. OTHER MARKET PARTICIPANTS

Thus far, we have analyzed the positions of C&C arbitrageurs and long index trackers and tested whether their long CLK20 positions were likely to have influenced inventory levels and price formation in the days preceeding the crash. This section considers two other categories of traders – speculators and hedgers – and conducts tests that shed light on the predominant nature of their positioning on CLK20 (long or short) ahead of the negative pricing – had they been predominantly long, their reverse trading on April 20, 2020 could have also contributed to the price crash. We also discuss the CFTC Interim Staff report published on November 23, 2020.

6.1 Speculators

Were speculators (e.g., CTAs and managed futures funds) likely to be long CLK20 ahead of the price crash? We see this as unlikely for two reasons. First, like index trackers, speculators do usually avoid physical delivery by rolling their positions to distant contracts a few weeks prior to maturity, thus evading exposure to illiquidity-driven price fluctuations. Second, various trading signals as early as March 2020 hinted towards poor forthcoming performance of CLK20, and thus, rational speculators ought to have been predominantly short this contract.

As an example, on March 31, 2020 (or 15 business days before maturity of CLK20; hereafter, *T*-15), and as detailed in Section 3 above, the crude oil supply was at a staggeringly high level while demand was very low, and accordingly, inventories at Cushing were quickly rising, hinting towards a price fall (Gorton et al., 2013). Relatedly, the futures-spot spread was positive and large at $4.03 (versus the 95th percentile of $1.41 from March 30, 1983 to June 29, 2020). Thus, the term structure of crude oil futures prices was upward-sloping and very steep at *T*-15, predicting a fall in CLK20 prices (Erb and Harvey, 2006; Gorton and Rouwenhorst, 2006).

Likewise, the 50-day average return of CLK20 was very low on day *T*-15, at -2.11% (compared to the 5th percentile of the distribution of all contracts from March 30, 1983 to June 29, 2020 at -0.56%). According to the *momentum* literature, this highly negative momentum signal predicted poor performance of CLK20 in the run-up to maturity (Miffre and Rallis, 2007; Moskowitz et al., 2012). Moreover, the *basis-momentum* signal took at *T*-15 the very negative value of -0.3627% (the 5th percentile from March 30, 1983 to June 29, 2020 was -0.0620%) also predicting a price drop. Finally, the *relative basis* signal at *T*-15 took a negative value of -$0.85 (compared to a 5th percentile of -$0.52 from March 30, 1983 to June 29, 2020). Thus, the term structure of WTI futures prices was unusually concave, suggesting that the-then front-maturity contract (CLK20) was overpriced. Table 4 summarizes all predictive signals over the entire sample period. Since speculators rely on some (or a mix) of the above signals as predictors of futures prices, it is reasonable to assume that they took short (instead of long) positions in CLK20 on March 31, 2020, in the hope of closing them nearer maturity at lower prices, and thus, earning a premium. By entering a reversing long trade closer to maturity, these short speculators offered long traders (who were seeking to reverse their positions) part of the liquidity they craved and thus, if anything, they favourably prevented the price crash from being even more dramatic than it was.

[Insert Table 4 around here]

In line with the hypothesis of Minsky (1977) that "stability is de-stabilizing", Danielsson et al. (2018) show that major global banking crises occur in low volatility environments. Likewise, it is possible that crude oil speculators, observing the low WTI volatility in the early stage of the COVID-19 pandemic (Bakas and Triantafyllou, 2020), as well as the low spot price of oil due to contango,[13] took longer CLK20 positions than they would have otherwise. In other words, the possible rise in risk-taking appetite of long speculators in periods of low volatility and their reversing trade near maturity could potentially explain or contribute to the price crash.

To test this hypothesis, we estimate the following regression model:

$$L_t - S_t = \alpha + \beta h_t + \beta^{-} h_t D_t + \sum_{k=1}^{K} \theta_k Ctrl_{k,t} + \gamma(L_{t-1} - S_{t-1}) + \varepsilon_t, \quad (5)$$

where L_t (S_t) are the week *t* long (short) WTI position of large non-commercial traders (or speculators), h_t is the week *t* conditional GARCH (1, 1) volatility of WTI returns,[14] D_t is a dummy variable equal to 1 when conditional volatility is below its full-sample average, $Ctrl_t$ are the control variables (futures-spot spread, momentum, basis-momentum, relative basis, EPU, ADS, and VIX) and ε_t is an error term. A positive and significant $\hat{\beta}^{-}$ would support the view that low volatility induces longer WTI positions by speculators and thus a higher risk-taking appetite for cheap spot oil in contangoed markets.

Table 5 presents the coefficient estimates. The results indicate $\hat{\beta}^{-} < 0$, and thus, speculators typically take shorter positions when volatility is low (i.e., below its full-sample average); namely, in periods of contango. Thus, the increase in the risk-taking behavior of speculators in periods of low volatility would translate in our context into them taking shorter (and not longer) positions than they would otherwise.[15] This evidence does not allow us to argue that speculators contributed to the anomalous negative price of CLK20 by increasing their long positions before the crash and by subsequently reversing their trade on April 20, 2020.

6.2 What about Long Hedgers?

Could one explanation for the negative pricing of CLK20 on April 20, 2020 be that many long hedgers (i.e., processors or users of crude oil) desperately sought to enter a reversing CLK20 trade one day before maturity and precipitated the negative pricing of the contract? We see this as unlikely for two reasons. First, long hedgers are not interested in taking delivery at Cushing (as this would imply transportation costs to their operational base), and

[13] According to the theory of storage (Pindyck, 2004; Geman and Ohana, 2009; Gorton et al., 2013, to cite only a few papers), abundant inventory levels (or contango) are associated with low risk of stock-outs and thus low volatility. Vice versa, scarce inventory levels (or backwardation) come hand-in-hand with high risk of stock-outs and thus high volatility. Unreported results confirm that low (high) WTI volatility comes hand-in-hand with low (high) WTI futures returns, and thus contango (backwardation).

[14] Since the CFTC collects speculators' positions every calendar Tuesday, the conditional volatility h_t is estimated using Tuesday-to-Tuesday price changes in front-end WTI contracts.

[15] This result corroborates our findings from the signals (inventory level, basis, momentum, basis-momentum, and relative basis) all of which pointed towards a contangoed market before the crash, predicting falling futures prices, and thus attracting short speculative positions.

thus they typically close their positions weeks before maturity when liquidity is abundant. Second, as the WTI market entered a phase of deep contango, long hedgers had an incentive to decrease their long hedge, rather than increase it (see Anderson and Danthine, 1983; Stulz, 1996 on selective hedging).[16] Some processors and consumers of WTI crude oil might even have considered the possibility of not hedging at all, hoping to buy crude oil in the spot market at a very low price for when needed in the near future. Indeed on April 20, 2020, traders in the "Product/Merchant" group held long positions on CLK20 that represented merely 14.7% of the total long open interest on CLK20, and that percentage is considerably lower than the average long position that the "Product/Merchant" group typically held one day before maturity of the previous 12 WTI futures contracts at 52.5% (CFTC *Interim Staff Report*, November 2020). In sum, relatively few long hedgers ended up in the dire situation of holding long CLK20 positions on April 20, 2020.

6.3 The November 23, 2020 CFTC Interim Staff Report

On November 23, 2020, the CFTC published its highly anticipated Interim Staff Report, in which it shared its views about the circumstances that could have triggered the negative CLK20 price. However, the CFTC merely described the long and short CLK20 open interest positions per trader category without any clear indication of which trader or traders' category could be behind the negative price. As the CFTC Chairman, Heath P. Tarbert, said: "While some may have hoped for a more definitive analysis, we simply cannot provide that at this time, just as we cannot confirm or deny media reports of investigations tied to these events." From the report, only the unusual proportion of total long positions on April 20, 2020 held by "non-reportable" traders (with open interest below the reporting level specified by the CFTC) and "other reportable" traders (such as, e.g., family offices, wealthy foundations, or proprietary trading houses) were emphasized.

7. EXPLAINING THE DRAMATIC PRICE SWING OBSERVED ON APRIL 20, 2020

The previous sections analyzed the likely positions of various market participants in the days and weeks preceeding the price crash. In this section, we analyze the dramatic price swing from $18.27 at the close of trading on April 17, 2020 to -$37.63 at the close of trading on April 20, 2020 and the concomittant drop in open interest from

[16] Selective hedging is a common practice among hedgers (consumers, processors, and producers), who simultaneously seek to reduce the risk of their spot position (risk minimization) and earn a premium by forecasting price changes (speculation). Through selective hedging, they under- or over-hedge the risk of their spot exposures.

108,593 to 13,044. Such drops were unheard of. This suggests that many long traders were caught in the fire and had to precipitously close their positions, as anecdotal evidence reported in the press suggested.[17]

We bring forward four elements of response that could explain the price crash. These elements relate to a lack of storage, a squeeze of liquidity, the TAS mechanism, and an increase in margin calls. First, over the period preceding the crash, and as C&C trades intensified, storage at Cushing became scarce.[18] As Figure 3 demonstrates, storage utilization there was at 76% in April 17, 2020, right before the crash. At that stage, anecdotal evidence reported in the press[19] hinted towards an absence of spare storage capacity at Cushing. Some even argued that at the end of Friday April 17, 2020, the open interest of CLK20 (at 108,593 thousand barrels, for 108,593 contracts exceeded the capacity remaining at Cushing (at 18,305 thousand barrels) by a factor of six, which is most unusual.[20] As a result, any trade that would long WTI crude oil using CLK20 could not be physically realized because the oil could not be stored. Long CLK20 traders were thus left with the following stark choice: either paying exorbitant storage costs at maturity (if oil tank leasing was at all feasible) or entering a reversing trade at all costs before maturity just to avoid taking delivery, even if that implied selling at the negative price of -$37.63 per barrel. In effect, the second alternative amounts to closing long CLK20 positions by paying $37.63 per barrel to a counterparty with a storage facility (the counterparty thus receives both the barrels of oil and the payment). Long CLK20 traders on April 20, 2020 were willing to pay in order to get rid of their long contracts so as to avoid the obligation of having to take physical delivery.

Another factor that exacerbated the severity of the price crash relates to the lack of liquidity of CLK20 on April 20, 2020 and, consequently, to the difficulty faced by futures traders to close at reasonable prices the unusually large number of positions that were still open at that stage. To demonstrate the illiquidity of CLK20, Figure 5 plots the one-minute transaction prices (left-hand side) and quoted spreads (right-hand side) of CLK20, and those of its two adjacent contracts, the April 2020 (CLJ20) and the June 2020 (CLM20) contracts, over their two final days of

[17] "Regulator fines Bank of China over loss-making product linked to crude oil," *Reuters,* December 5, 2020; "China's 'Crude Oil Treasure' promised riches. Now investors owe the Bank," *New York Times*, May 21, 2020; "In depth: A bitter $1.4bn lesson on commodity price speculation," *Nikkei Asia*, April 28, 2020.

[18] Another telltale sign of storage buildup is that lease rates soared for very large crude carriers (VLCCs) as onshore space became increasingly scarce. VLCC rates jumped to $120,000 per day by March 29, 2020, up from about $40,000 at the start of March. See, e.g., "Oil tanker rates double as demand for storage and transport resurface," *Reuters*, March 30, 2020.

[19] See e.g., "Oil plunge sets off search for tanks, revives dormant Cushing storage trade," *Reuters*, March 17, 2020; "Oil market shows fear that U.S. is running out of storage space," *Bloomberg*, March 25, 2020; "Oil ground zero: Running out of storage," *Council on Foreign Relations*, April 6, 2020.

[20] To put this factor of six into perspective, note that the open interests of the WTI contracts with maturity in February 2020, March 2020, April 2020, June 2020, and July 2020 only exceeded, two days before maturity, the available storage at Cushing by an average factor of 1.5. See "WTI negative price and Cushing, Oklahoma, crude oil storage capacity: The importance of 15%," *Kapsarc*, May 28, 2020.

trading.[21] The quoted spread of CLK20 (Panel B) started to increase at around 12:00 p.m. Eastern Time, which coincided with the acceleration of CLK20 price decline,[22] and reached levels higher than $2, which is extremely high relative to the average 2-day spreads of CLJ20 ($0.05), CLK20 ($0.37), and CLM20 ($0.06). The liquidity (long) squeeze of CLK20 that prevailed on April 20, 2020 prevented traders from easily closing their positions, which, alongside the absence of storage, resulted in the observed negative pricing.

[Insert Figure 5 around here]

As a third contributing factor, we argue that the TAS system could have exacerbated the negative pricing. Dan M. Berkovitz, Commissioner at the CFTC, said in his March 15, 2021 statement that some market participants could have benefitted from the TAS mechanism by i) buying CLK20 at TAS price during the April 20, 2020 trading day, ii) simultaneouly selling CLK20 outright so as to push the TAS price down, and iii) leaving both positions to cancel each other at settlement time. By so doing, the traders willing to long CLK20 at TAS (such as proprietary traders, market makers, or arbitrageurs) and short CLK20 outright earned handsome profits and precipitated the price fall.[23] This suggests a possible manipulation of the settlement price by participants willing to engage in the aforementioned trade and therefore the possible need for regulation to ensure the integrity of the TAS pricing mechanism in the future. This calls for limits on the netting of speculative TAS positions with speculative outright positions during the contract delivery month to prevent price distortion and market abuse.

A final factor that precipitated the price swing relates to the margin calls that long CLK20 traders fear they might incur (e.g., the price of CLK20 dropped by 43.62% at midday on April 20, 2020 relative to the previous day's settlement price). To avoid a larger loss due to these margin calls, some capital-constrained long CLK20 traders must have chosen to close their positions before maturity, again precipitating the price crash.

8. CONCLUSIONS

[21] The quoted spread measures the compensation earned by market makers for offering liquidity: the higher the quoted spread, the less liquid the market. It is calculated as the difference between the best ask and best bid futures prices sampled at a one-minute frequency. We filter out quoted spread values i) equal to or below 0 and ii) exceeding $5 (Chordia et al., 2001). Similar unreported results were obtained using the effective spread.

[22] Dynamic circuit breaks halted trading for a few minutes (particularly between 1:00 p.m. and 2:30 p.m. ET) but did not not stop the price fall.

[23] For instance, at 1:15 p.m. E.T. on April 20, 2020, the CLK20 TAS price was equal to the settlement price minus $0.10 (see Figure 19 in the CFTC's Interim Staff Report, November 2020) and the CLK20 outright price was $4.34. The strategy based on the TAS mechanism thus yielded a profit of $1{,}000 \cdot (\$4.34 - (-\$37.63 - \$0.10)) = \$42{,}070$ per CLK20 contract.

On April 20, 2020, the price of the NYMEX WTI May 2020 futures contract crashed into very negative territory. Our paper tries to investigate what happened not only in the few weeks preceeding the negative pricing but also on the day the price turned negative.

A disastrous blend of macroeconomic and geopolitical conditions, such as a rising surplus triggered by geopolitical tensions and demand obliterated by COVID-19 lockdowns, moved the WTI futures market into a super contango early April 2020. The steep upward-sloping term structure of WTI futures prices, in turn, attracted a splurge of C&C arbitrages with a perverse feedback effect. The increase in C&C arbitrage contributed to boosting storage utilization at Cushing, the storage hub where the NYMEX WTI futures contract is settled. On April 20, 2020, upon the realization that there was no spare storage facility, long CLK20 traders who had not previously secured storage entered a reversing trade that led to a panic selloff upon the realization of the impossibility of taking physical delivery. Aggravating factors included a lack of liquidity, the staggering margin calls faced by long CLK20 traders as the price dropped, as well as the likely price distortion that occurred as a consequence of the TAS mechanism. We also investigated claims by commentators who blamed large index trackers for distorting the price. Our evidence shows that these claims were unwarranted: Large index trackers such as USO did not cause the negative pricing or widen the futures-spot spread by rolling their positions to more distant contracts ahead of maturity.

Among the practical implications of this research are lessons to traders with long front-end positions right before maturity, calling them to exert caution in super-contangoed futures markets, as at maturity the long position can suddenly become unfeasible if the asset cannot be physically stored. Our findings thus call for regulators to monitor the long positions of traders close to delivery so that they do not dislocate the natural convergence of the futures and spot prices at maturity. To ensure the integrity of the TAS pricing mechanism, it might also be of interest for regulators to limit the netting of speculative TAS positions with speculative outright positions during the contract delivery month.

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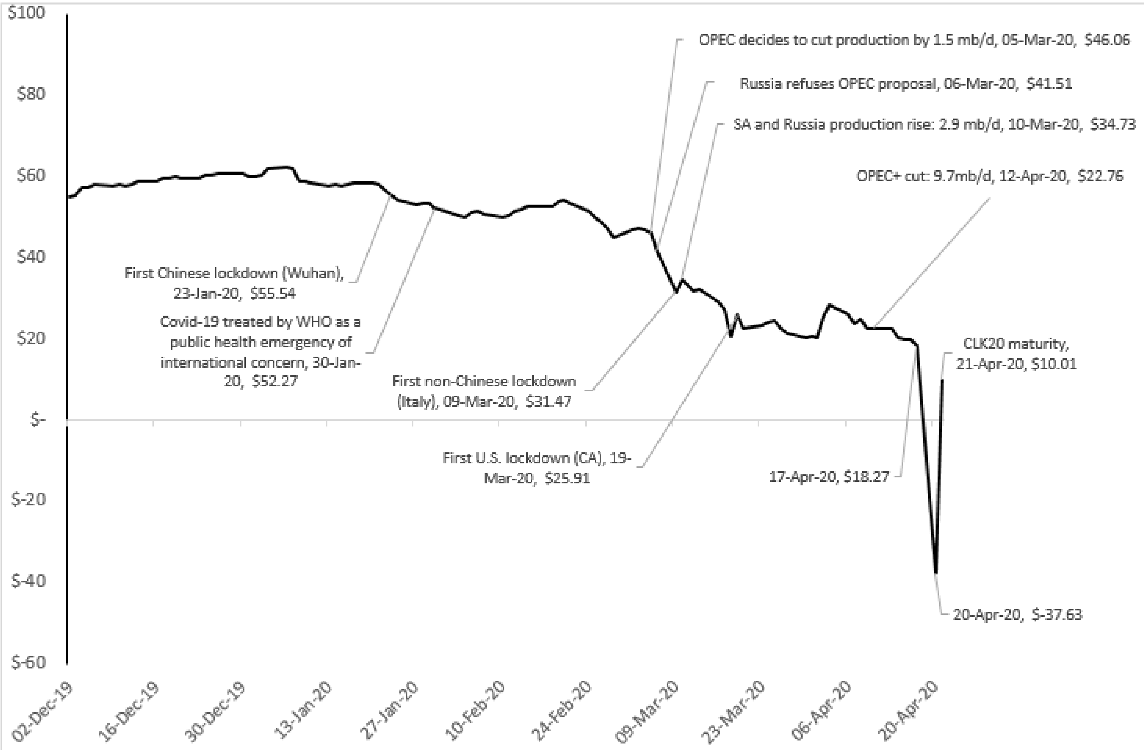
Figure 1: CLK20 Prices and WTI Crude Oil Supply and Demand Fundamentals

Panel A plots the evolution of CLK20 prices alongside various economic and geopolitical events. Panel B plots the futures-spot spreads of WTI and Brent crude oil, with the horizontal line denoting the 95th percentile of the distribution of WTI spreads from March 30, 1983 to June 29, 2020.

Panel A: Timeline of economic and geopolitical events and the price of CLK20



Panel B: Evolution of futures-spot spreads

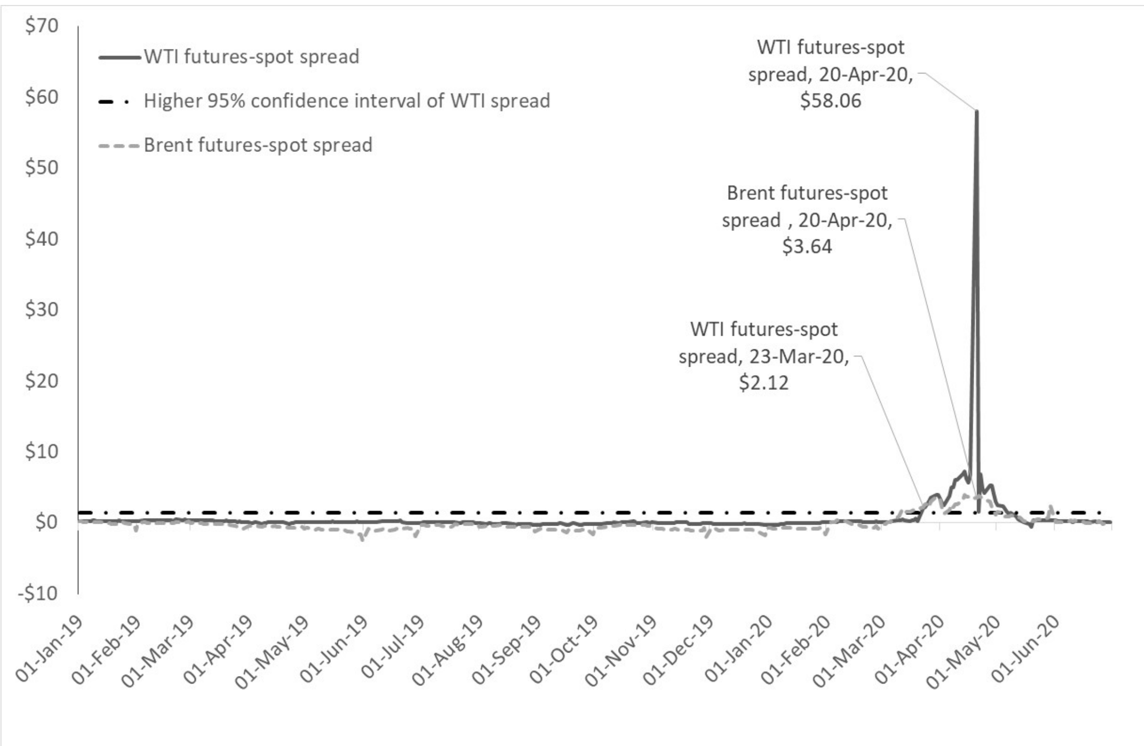
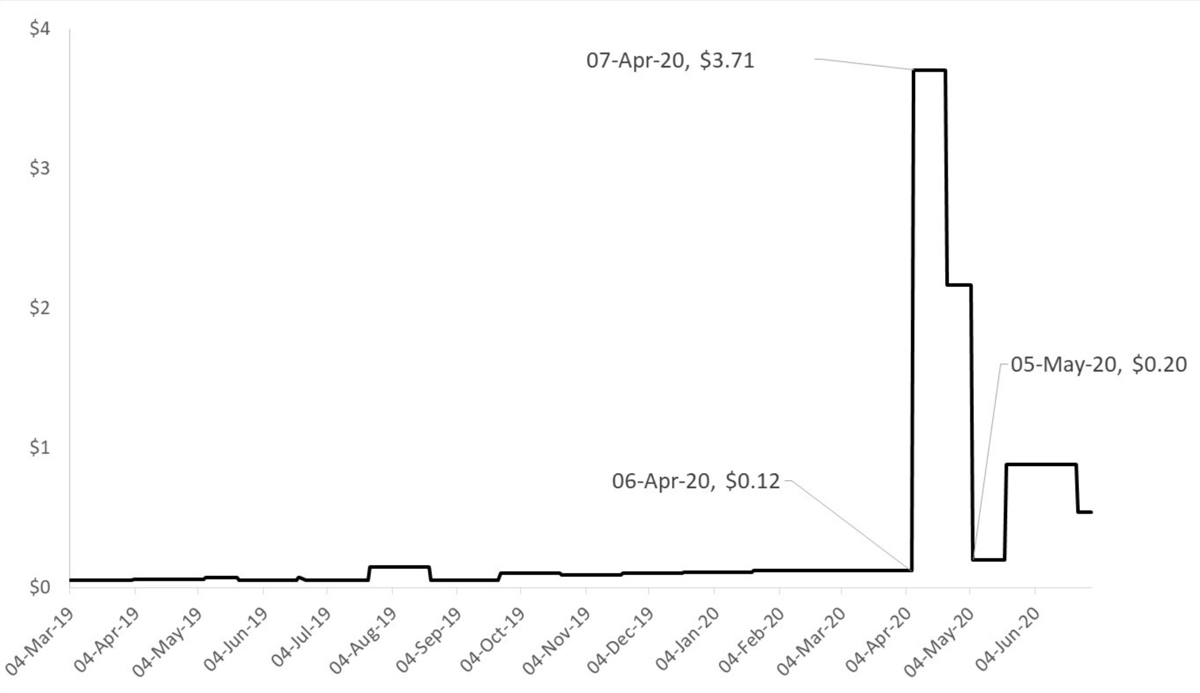


Figure 2: Cost of Storage and C&C Arbitrage

Panel A plots the daily settlement prices of front-end ICE Permian WTI storage futures over a period from March 4, 2019 to June 29, 2020. Panel B presents the P&L of cash and carry arbitrage strategies right before the price crash, namely over a period from January 2, 2020 to April 17, 2020. The P&L calculations are based on storage costs set to either 0.74% of the spot price (Stancu et al., 2021) or the settlement price of Permian WTI storage futures.

Panel A: Settlement prices of Permian WTI storage futures



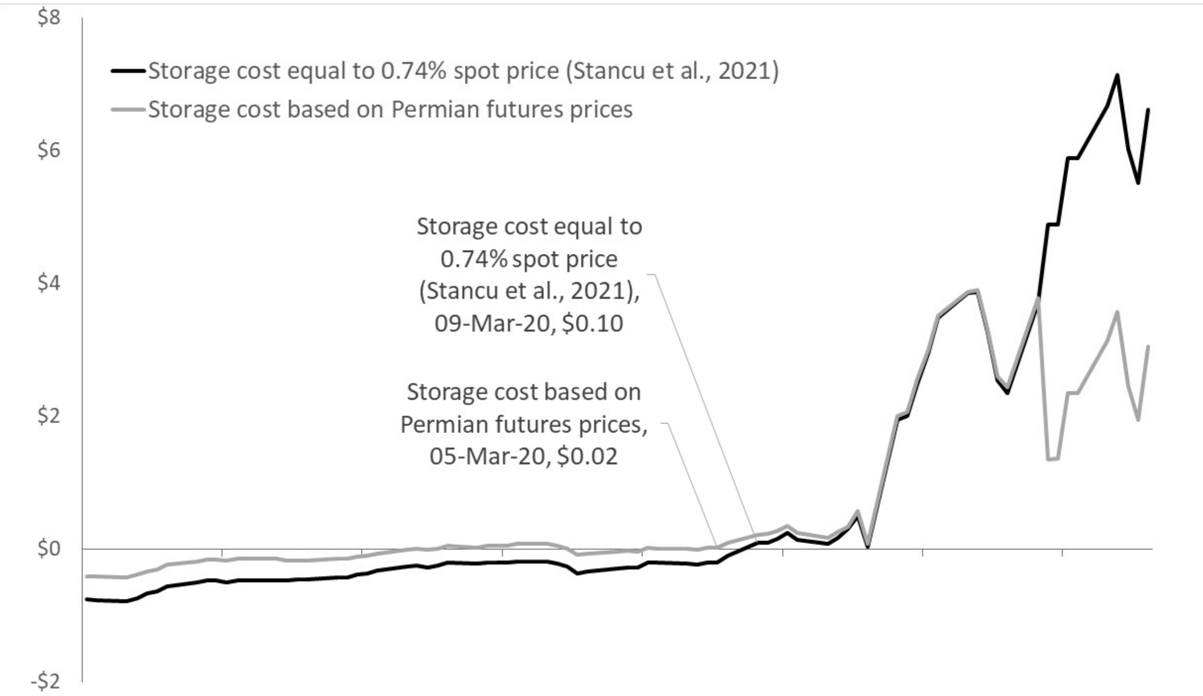


Figure 3: Crude Oil Storage Capacity Utilization at and Outside Cushing

The figure plots the weekly crude oil storage capacity utilization at and outside Cushing. The sample is from January 17, 2020 to June 26, 2020.

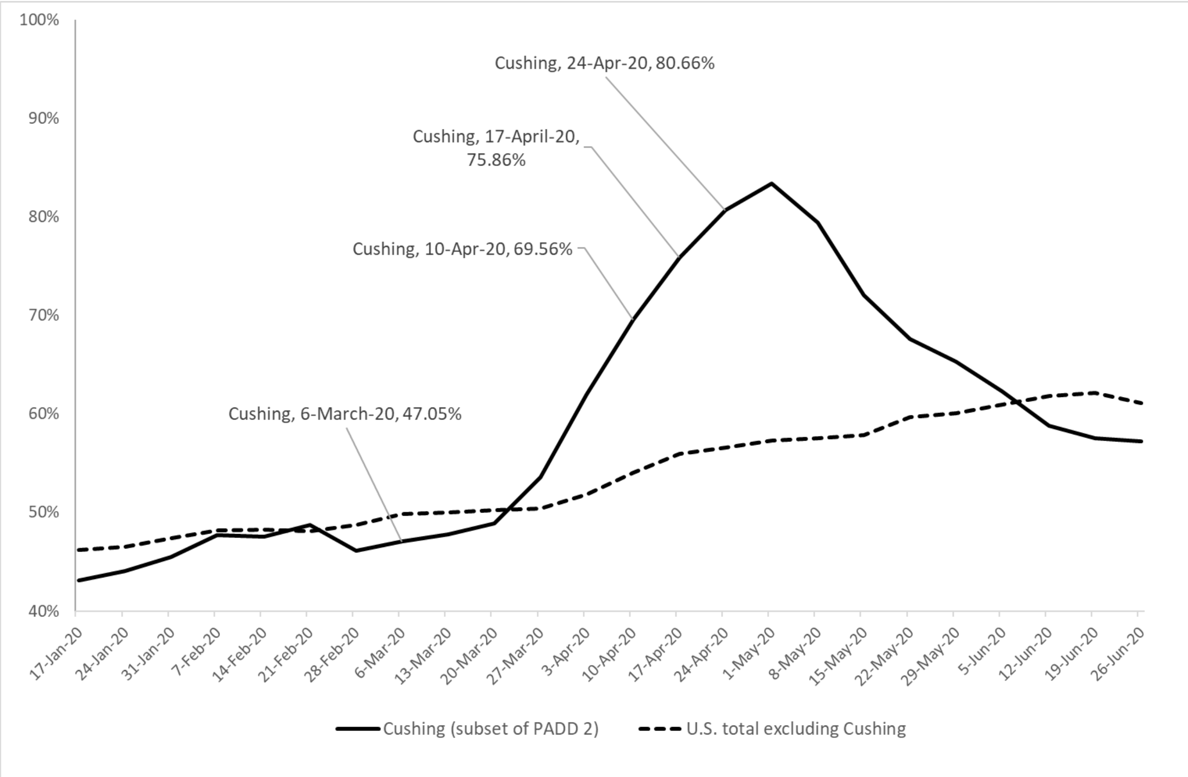
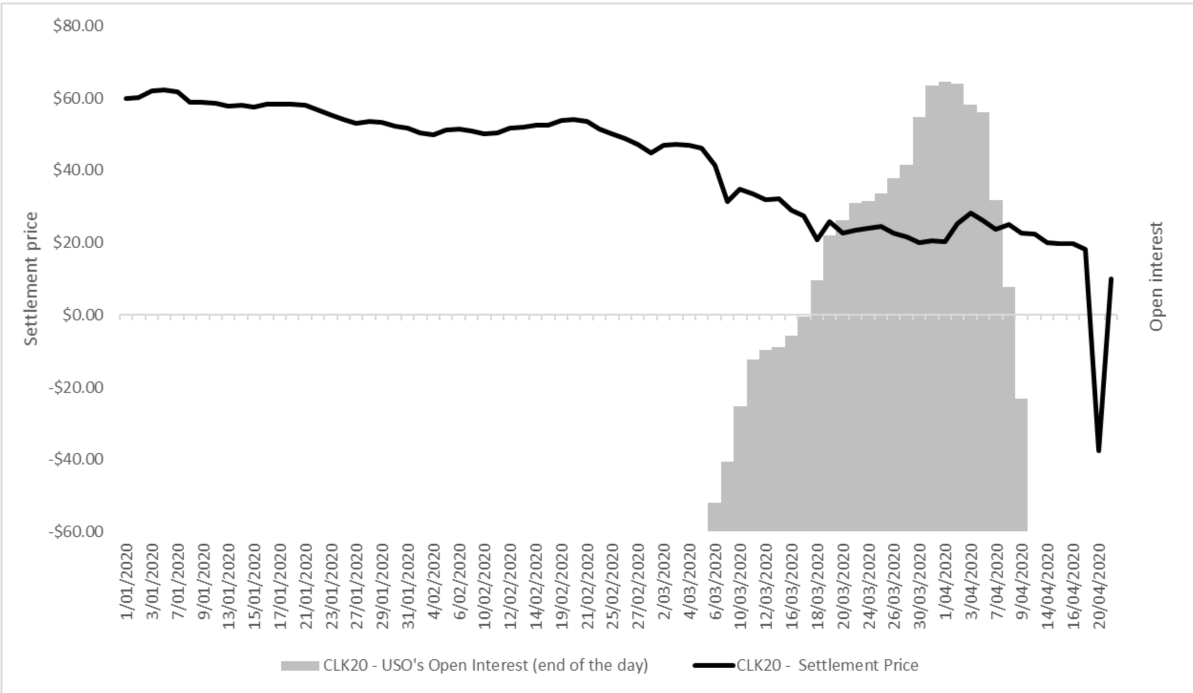


Figure 4: WTI Crude Oil Futures Prices and USO Trading

Panel A plots the daily CLK20 settlement price (left axis) and USO open interest (right axis) from January 1, 2020 to April 21, 2020; the latter has been anonymized for confidentiality reasons. Panel B plots for the pool of 148 WTI contracts ever held by USO over the sample period, the maximum, median, and minimum of USO open interest over the 50 days preceeding their maturity (T).

Panel A: Price of May 2020 delivery contract and USO's open interest



Panel B: Distribution of open interest across the 148 WTI contracts ever held by USO

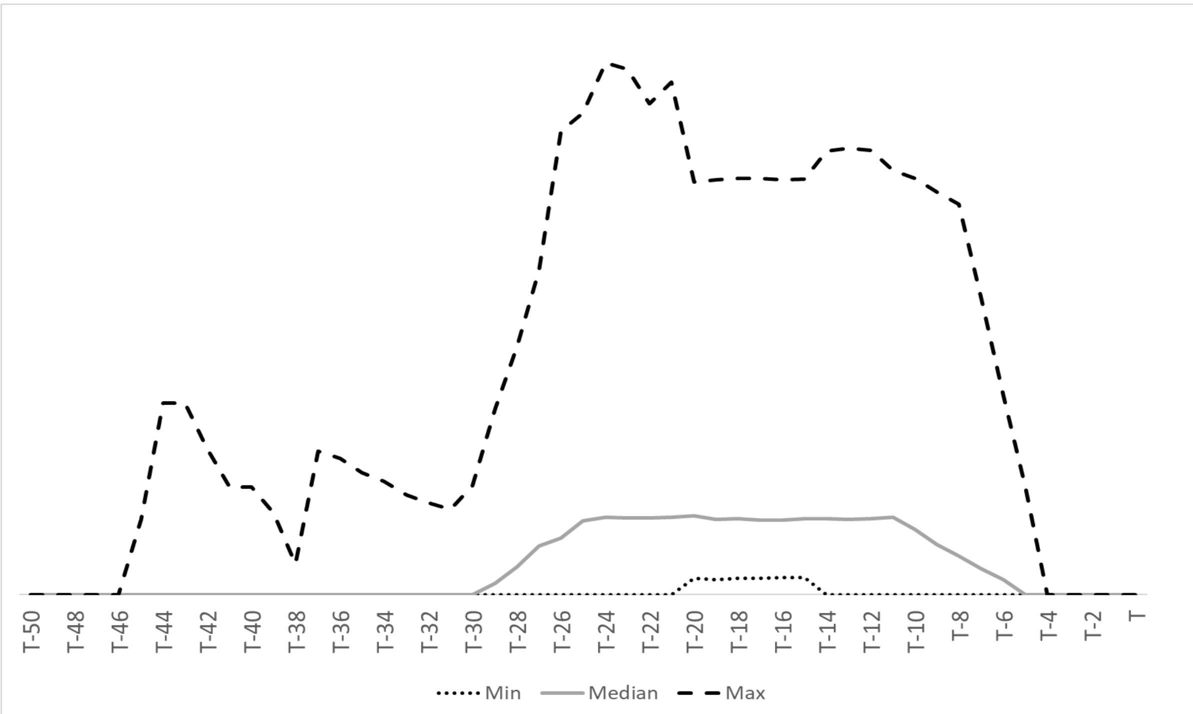
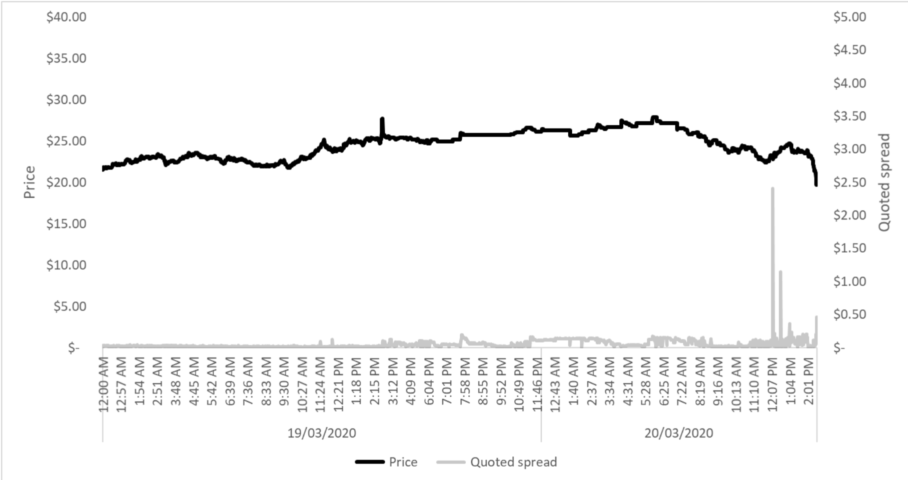


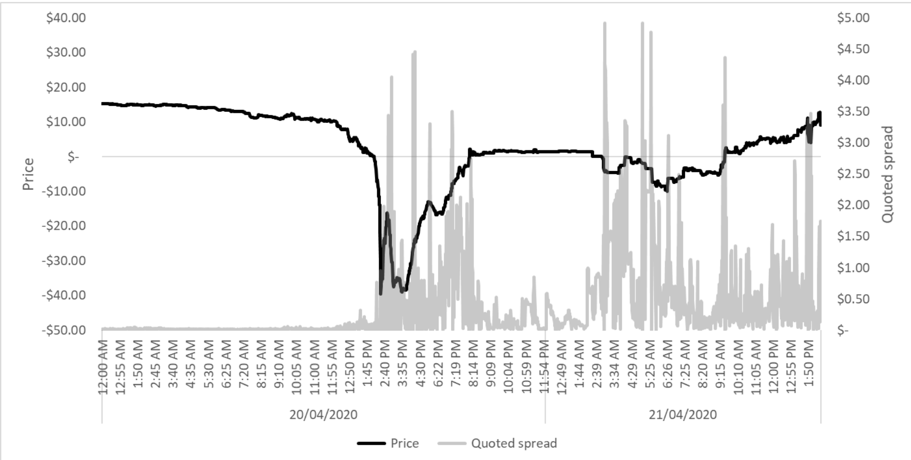
Figure 5: Liquidity Squeeze

The figure presents the transaction prices and quoted spreads of the April 2020 (CLJ20), May 2020 (CLK20), and June 2020 (CLM20) WTI contracts, sampled at a one-minute frequency over their last two days of trading.

Panel A: CLJ20



Panel B: CLK20



Panel C: CLM20

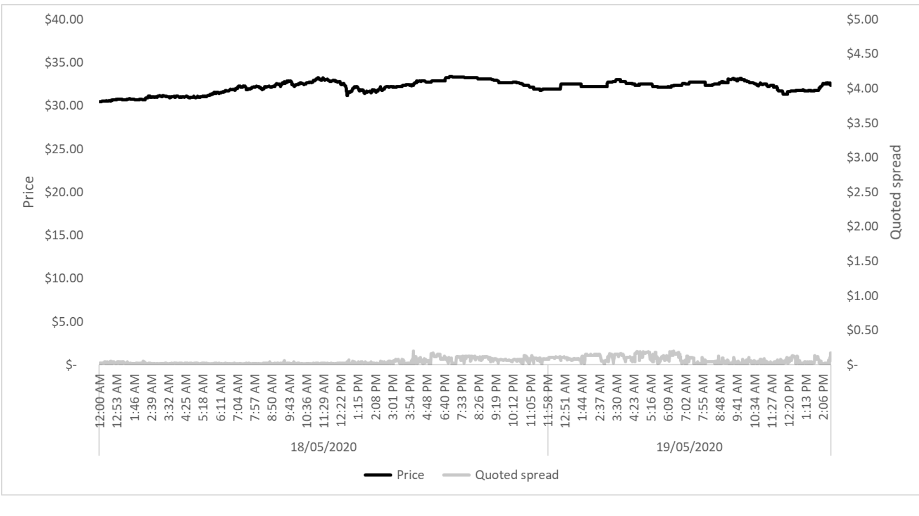


Table 1: Impact of changes in crude oil spreads onto changes in inventory

The table reports estimated coefficients and Newey–West h.a.c. robust *t*-statistics from a regression of weekly changes in crude oil inventory onto weekly changes in contemporaneous and lagged futures-spot spreads. The regression includes i) a dummy variable D_t interacted with the spreads, $D_t = 1$ in the period March 6, 2020 to April 17, 2020 and 0 otherwise and ii) a set of time *t* control variables as discussed in Section 2.2. The dependent variables are the changes in inventory at Cushing in Panel A and at all other U.S. hubs in Panel B. The sample period is April 9, 2004 to June 26, 2020.

	Panel A: At Cushing		**Panel B: All hubs but Cushing**	
	Estimate	*t*- stat	Estimate	*t*- stat
$b_{1,0}$	547.10	(4.44)	648.03	(1.56)
$b_{1,1}$	505.95	(3.60)	143.44	(0.50)
$b_{1,2}$	732.65	(5.88)	151.56	(0.52)
$b_{1,3}$	611.38	(5.22)	-380.01	(-1.48)
$b_{1,4}$	372.30	(3.75)	-401.86	(-1.92)
$b_{2,0}$	-182.25	(-0.67)	297.09	(0.30)
$b_{2,1}$	1075.12	(2.44)	1328.73	(0.97)
$b_{2,2}$	490.07	(1.50)	961.23	(0.92)
$b_{2,3}$	1486.69	(0.90)	13506.52	(2.54)
$b_{2,4}$	6262.39	(2.46)	36783.95	(4.16)
Joint hypothesis $b_{1,j} = 0$ for all *j*	37.95	(0.00)	7.88	(0.16)
Joint hypothesis $b_{2,j} = 0$ for all *j*	75.54	(0.00)	54.76	(0.00)

Table 2: Impact of USO positions on the price and volatility of CLK20

The table reports estimates of β_j and $\beta_{D,j}$ coefficients and robust *t*-statistics in parentheses for the panel Equations (2) and (3) based on daily returns and volatility changes, respectively, and daily USO flows (changes in open interest). The null hypotheses for the Wald test are i) H_0: $\beta_1 = \cdots = \beta_I = 0$, which states that USO's flows do not predict WTI futures returns (volatility changes) in general, and ii) H_0: $\beta_{D,1} = \cdots = \beta_{D,I} = 0$, implying that USO's flows do not predict the returns (changes in volatility) of CLK20 more than they predict the changes in price (volatility) of other contracts. Inferences are based on White robust standard errors clustered by period. Bold denotes 5% level significance. The estimation sample consists of the pooled daily returns, daily volatility changes, and daily USO open interest changes for all contracts traded by USO from October 24, 2008 to June 29, 2020. For ease of presentation, the β_j and $\beta_{D,j}$ estimates are multiplied by 10^6. *MW test* reports the *p*-value of the Modified Wald test for groupwise heteroscedastic in the error term (the null hypothesis is the residuals are groupwise homocesdastic). *Wooldridge test* reports the *p*-value of the Wooldridge AR(1) test for serial correlation in the error term (the null hypothesis is that the residuals are serially uncorrelated). *Cross correlation* reports the average pairwise contemporaneous correlation and *p*-value across residuals (the null hypothesis is that the residuals are cross-sectional uncorrelated).

	Panel A: USO flows and WTI/CLK20 returns		**Panel B: USO flows and WTI/CLK20 volatility change**	
Constant	0.001	(0.15)	**-0.086**	{-2.847}
Coefficients on USO lagged position change				
β_1	0.412	(1.75)	-3.205	(-1.77)
β_2	-0.427	(-1.71)	2.480	(1.78)
β_3			**-1.313**	(-2.36)
β_4			0.034	(0.07)
$H_0: \beta_1 = \cdots = \beta_I = 0$	3.25		7.68	
	{0.197}		{0.104}	
Coefficients on USO lagged position change x CLK20				
$\beta_{D,1}$	**-4.640**	(-1.96)	39.06	(0.95)
$\beta_{D,2}$	5.670	(1.90)	-48.19	(-0.72)
$\beta_{D,3}$			-3.63	(-0.05)
$\beta_{D,4}$			20.32	(0.31)
$H_0: \beta_{D,1} = \cdots = \beta_{D,I} = 0$	3.85		1.67	
	{0.146}		{0.796}	
Individual FE	Yes		Yes	
Month FE	Yes		Yes	
Adj-R^2	18.12%		22.35%	
MW test (null: groupwise homoscedastic)	{0.000}		{0.000}	
Wooldridge test (null: residuals serially uncorr)	{0.756}		{0.115}	
Cross correlation	0.885		0.870	
test (null: residuals cross uncorr)	{0.000}		{0.000}	
Observations	3,471		3,029	

Table 3: Impact of index trackers on futures-spot spreads

The table reports coefficients and associated Newey–West h.a.c. robust *t*-statistics from regressions of futures-spot spreads onto a dummy set to 1 for CLK20 and 0 otherwise and the set of control variables discussed in Section 2.2. The results are reported using the 5th to the 9th trading days of maturity months for the S&P-GSCI (Panel A), the 6th to the 10th trading days of maturity months for DJ-UBSCI (Panel B), and the rolling days of USO as specified by USCF (Panel C). The sample covers the period from October 24, 2008 to June 29, 2020.

	Panel A: S&P-GSCI		**Panel B: DJ-UBSCI**		**Panel C: USO**	
	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat
a_0	0.000	(0.485)	0.000	(0.253)	-0.022	(-1.229)
a_1	-0.001	(-0.095)	-0.005	(-0.882)	-0.357	(-1.216)
Futures spread$_{t-1}$	0.001	(1.920)	0.000	(1.013)	0.015	(1.313)
Momentum$_{t-1}$	-0.126	(-1.765)	-0.163	(-1.834)	2.292	(1.209)
Basis-Momentum $_{t-1}$	2.490	(1.219)	3.510	(1.484)	61.552	(1.252)
Relative basis$_{t-1}$	-0.004	(-3.779)	-0.001	(-0.519)	0.051	(3.256)
ADS$_{t-1}$	-0.001	(-1.976)	-0.001	(-1.517)	-0.023	(-1.494)
EPU$_{t-1}$	0.000	(0.023)	0.000	(0.716)	0.000	(1.264)
VIX$_{t-1}$	0.000	(-1.076)	0.000	(-0.843)	0.000	(-0.005)
Adj-R^2	36.550		3.013		33.011	

Table 4: Predictive signals for WTI futures prices

This table reports descriptive statistics of various signals used in the literature as predictors of futures prices: spread (difference between the futures and spot prices), momentum (50-day moving average spot returns), basis-momentum (difference between the 50-day moving average returns of the spot and futures contracts), and relative basis (difference between the front and second-maturity spreads). The sample period is from March 30, 1983 to June 29, 2020.

	Spread	Momentum	Basis momentum	Relative basis
Signal as of March 31, 2020	$ 4.03	-2.11%	-0.3627%	-$ 0.85
Mean	$ 0.10	0.00%	-0.0052%	-$ 0.05
Standard deviation	$ 1.01	0.35%	0.0527%	$ 0.65
5% percentile	-$ 0.98	-0.56%	-0.0620%	-$ 0.52
Median	$ 0.07	0.04%	-0.0032%	-$ 0.03
95% percentile	$ 1.41	0.44%	0.0593%	$ 0.43

Table 5: Was stability destabilizing?

The table presents coefficient estimates and associated Newey–West h.a.c. robust *t*-statistics from Equation (5). h_t is the week *t* conditional GARCH (1, 1) volatility, D_t is a dummy variable equal to 1 when conditional volatility is below its full-sample average, and the remaining variables are the controlling factors as discussed in Section 2.2. The sample period is from October 6, 1992 (due to the availability of WTI crude oil non-commercial CoT data) to June 23, 2020.

	Coefficient	*t*-stat	Coefficient	*t*-stat
a	3182.744	(2.23)	7100.126	(3.74)
h_t	-10.176	(-0.19)	62.956	(0.61)
h_t x D_t	-356.131	(-1.95)	-471.253	(-2.67)
Futures spread$_t$			1128.285	(1.17)
Momentum$_t$			867697.162	(3.57)
Basis-Momentum $_t$			-1256742.221	(-0.67)
Relative basis$_t$			3134.078	(1.24)
ADS$_t$			-1361.800	(-4.90)
EPU$_t$			-0.215	(-0.03)
VIX$_t$			-193.430	(-2.04)
L_{t-1} - S_{t-1}	0.996	(246.01)	0.993	(247.59)
Adj-R^2	98.974		98.999	