



# CRA Insights: Finance

CRA Charles River  
Associates

September 2020

## Primer on futures markets and spoofing allegations

### Introduction

The Dodd-Frank Wall Street Reform and Consumer Protection Act of 2010 defines spoofing as bidding or offering with the intent to cancel the bid or offer before execution.<sup>1</sup> In recent years, there has been a surge in the number of cases filed by the Department of Justice (DOJ), the Commodity Futures Trading Commission (CFTC) and the Securities and Exchange Commission (SEC) on alleged spoofing-related matters. Many of these allegations have been made about activity in futures markets. In this article, we provide background for readers to help them understand futures markets and orders that regulators have alleged to be spoofing attempts. We also provide information on how the markets have evolved over the 10 years from 2009 to 2018.

### A primer on futures markets and the limit order book

A futures contract is an agreement to buy or sell an asset at a predetermined price at a prespecified time in the future. These contracts are listed on an exchange, such as the Chicago Mercantile Exchange (CME). When futures contracts are traded, the transaction is between anonymous parties; the buyer is not aware of the identity of the seller, and vice-versa. The futures contract is based on the price of an underlying asset, such as gold or interest rates, as of the pre-specified delivery date of the futures contract.

An exchange will typically have futures contracts with multiple delivery dates specified. Some of these contracts will be more liquid than others; in many futures categories, the nearest delivery date in time will be the most heavily traded contract, since it will most closely reflect the current value of the underlying asset. Futures exchanges also list spread products, which allow traders to buy futures contracts with one delivery date and sell futures contracts with another, thereby allowing traders to capture the spread between the two contracts.

---

<sup>1</sup> Dodd-Frank Wall Street Reform and Consumer Protection Act, Public Law 111-203, July 21, 2010, Section 747, p. 1739. The Commodity Futures Trading Commission (CFTC) interprets the statute and provides the following examples of spoofing: (i) submitting or canceling bids or offers to overload the quotation system of a registered entity, (ii) submitting or canceling bids or offers to delay another person's execution of trades, (iii) submitting or canceling multiple bids or offers to create an appearance of false market depth, and (iv) submitting or canceling bids or offers with intent to create artificial price movements upwards or downwards. CFTC Anti-disruptive Practices Authority, Interpretive Guidance and Policy Statement RIN 3038-AD96, effective May 28, 2013.

When a trader wishes to trade a contract on an exchange, there are two primary types of orders that they can place. The trader can place a *market order*. This order type is filled immediately at the best price available in the market. Alternatively, the trader can place a *limit order*. A limit order says that they will buy (sell) a contract only at a specified price or lower (higher). A limit buy order is called a “bid.” A limit sell order is called an “ask” or an “offer.”

An exchange will match bids and offers according to price. For example, if one trader has a bid for a gold futures contract at \$1,199.3 per ounce and another has an offer for the same gold futures contract at \$1,199.3 per ounce, the two orders are matched, and traders execute a trade with each other. For limit orders that are not matched, the exchange maintains a list, or a “book,” of the outstanding limit orders that have been placed for a contract. The book is continually updated as orders are placed, modified, canceled, and filled. If a trader places a limit order that can be immediately matched based on the limit order book, this limit order is called a “marketable limit order.” The order will be filled, to the extent possible, with the orders resting in the limit order book, and any unfilled portion will then be added to the limit order book.

**Table 1: Top 10 levels of the gold futures order book on September 10, 2018 at 10 AM UTC<sup>2</sup>**

Number of Orders	Bid Quantity	Price (\$)	Ask Quantity	Number of Orders
		1,200.3	44	27
		1,200.2	38	25
		1,200.1	33	23
		1,200.0	57	35
		1,199.9	35	26
		1,199.8	47	32
		1,199.7	41	31
		1,199.6	45	25
		1,199.5	58	29
		1,199.4	31	16
17	24	1,199.3		
29	44	1,199.2		
26	40	1,199.1		
36	54	1,199.0		
25	40	1,198.9		
27	40	1,198.8		
19	47	1,198.7		
20	33	1,198.6		
26	45	1,198.5		
19	33	1,198.4		

The gold futures order book on September 10, 2018 at 10 AM UTC is shown in Table 1. Market participants can see the number of orders that have been placed at a given price level and the total quantity of contracts that are available to be traded at that price level. For instance, there are 17 buy orders for a total of 24 contracts at \$1,199.3, and 16 sell orders for a total of 31 contracts at \$1,199.4. The best bid is equal to \$1,199.3 and the best ask is equal to \$1,199.4 at that instant. If a market participant places a marketable buy order at \$1,199.5 for 100 contracts, the marketable order would be matched to the 31 lots at \$1,199.4 and 58 lots at \$1,199.5, for a total of 89 lots. In

<sup>2</sup> CME Market Depth Data, CRA analysis.

the next update of the order book, the best bid would become \$1,199.5 for one order and the remaining 11 contracts of the original order.<sup>3</sup>

A portion of the limit order book is visible to market participants who use this information to inform their order placement and trading decisions. Traders may place orders electronically on the CME exchanges or may trade futures contracts directly with each other or through intermediaries via voice trading. The CME provides historical information regarding the limit order book for its electronic market, which we have used for our analysis.

When placing a bid or an offer, a trader will specify the quantity of contracts that they are willing to trade along with the price level at which the trader is willing to execute that trade. The CME specifies a contract unit, or “lot” size, for each of its products. For example, one 10-year US Treasury futures contract has a face value at maturity of \$100,000 and one gold futures contract represents 100 troy ounces of gold. The CME also specifies price intervals, or “tick sizes,” for which the products may be quoted. For example, 10-year US Treasury futures contracts are quoted in percentage points of par and may be quoted in price increments of 1/64 of a percentage point, and gold futures contracts are quoted in US dollars per troy ounce of gold and may be quoted in \$0.10 increments.<sup>4</sup> In Table 1, the difference between the first and second best bid is equal to \$0.1 for a troy ounce, which is equal to \$10 per contract, since each contract is for 100 troy ounces.

Exchanges typically allow traders to specify how their bids and offers appear to other market participants. A visible order is one where the full quantity on an offer is visible. For example, if a trader places a visible offer for 35 Eurodollar futures contracts at 99.30, and this was the only offer at this price level, the total quantity of offers at 99.30 that the exchange publishes would be 35 contracts. Alternatively, a trader may specify that their order is an iceberg order, where a predefined quantity is shown to market participants. If the previous example were an iceberg offer showing just one contract, the total quantity of offers at 99.30 that the exchange published to the rest of the market would only be one contract. However, if there was a market order to buy, this would be filled by the full 35 contracts on offer. Iceberg orders can be used by traders to avoid fully revealing their intentions to the rest of the market. In Table 1, there are 17 buy orders for a total of 24 contracts at \$1,199.3. For instance, if 10 out of 17 orders are 20-lot iceberg orders of which only one lot is visible to the market, the total amount available at that level would be 214 contracts.<sup>5</sup>

Exchanges also allow orders that may not show up in the visible limit order book at all. For example, a trader may place a “stop-loss” order, which is contingent on the market trading at a pre-specified price. A stop-loss order could be specified such that if the traded gold futures price fell to \$1,074.2, an order to sell 100 lots of gold futures would be entered. In addition, a trader may place a “fill-and-kill” order on the CME. This order type signifies that if the order can be immediately partially or fully executed at the specified price level, it will be so filled; any remaining unfilled portion will then be canceled (or “killed”). Similarly, a “fill-or-kill” order will require that an order be immediately fully executed at the specified price level; if it cannot be immediately and completely filled, it will be canceled in full. Such orders only affect the visible limit order book to the extent that

---

<sup>3</sup> The foregoing assumes that none of the corresponding sell orders are “iceberg” orders and there is no other market activity that affects the order book.

<sup>4</sup> CME Group, 10-Year T-Note Futures Contract Specs, [https://www.cmegroup.com/trading/interest-rates/us-treasury/10-year-us-treasury-note\\_contract\\_specifications.html](https://www.cmegroup.com/trading/interest-rates/us-treasury/10-year-us-treasury-note_contract_specifications.html) and CME Group, Gold Futures Contract Specs, [https://www.cmegroup.com/trading/metals/precious/gold\\_contract\\_specifications.html](https://www.cmegroup.com/trading/metals/precious/gold_contract_specifications.html).

<sup>5</sup>  $214 = 10 \text{ iceberg orders with 1 lot per order visible} \times 20 \text{ lots total quantity per order} + 14 \text{ lots that come from the remaining 7 orders.}$

they result in trades. If the orders are placed and immediately killed, they are not reflected in the order book.

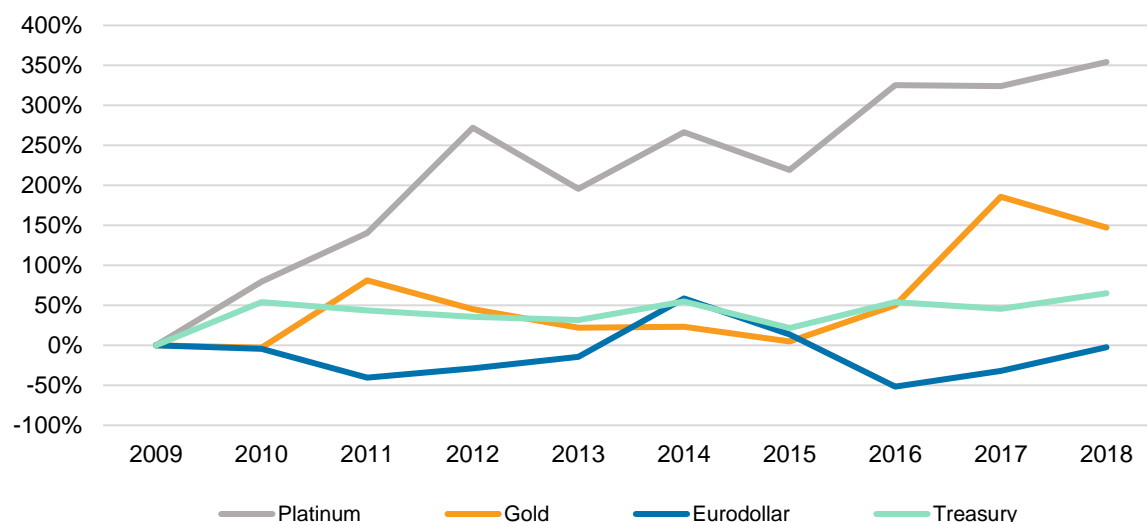
In the next section, we provide certain summary information about four different contracts over a 10-year period from 2009 to 2018 using data that is publicly available from the CME containing aggregated information on contracts that are bid, offered, and traded at each price level during and at each moment during the day. We start by describing the data that we use and then describe the markets for the contracts we study. The CME, regulators, and the DOJ have access to much more detailed datasets that contain specific information about each individual order that was placed on the exchange. This information allows them to identify orders placed by individual traders and is the basis for many of the enforcement actions in futures markets.

## Daily volume and intraday timing of new order placements

Our analysis in this article is based on the publicly available historical market-depth data from the CME for gold futures, platinum futures, Treasury 10-year note futures, and Eurodollar futures. The CME provides real-time updates up to the top 10 levels of the limit order book (top 5 levels for the Eurodollar market), the number and visible quantities of bids and offers, and trade executions. This is similar to the data from the exchange that market participants would be able to observe in real time.

We focus on the order book data for these four products because they represent some of the products for which settlements have been reached in cases alleging spoofing, and reflect markets with a range of average daily trading volume. We analyze the second week of September every year from 2009 to 2018. This allows us to analyze a relatively consistent sample of market activity over a 10-year period so that we can observe trends in the market over time. The second week in September is characterized by a single contract in each market that constitutes most of the market activity for the relevant product in those times of the year. We analyze the trades and order book of the contracts expiring in December of each year for gold and Treasury 10-year note futures. For Eurodollar futures, we analyze the trades and order book of the contract expiring in December of the subsequent year, while for platinum futures we analyze the trades and order book of the contract expiring in October of each year, since those contracts have the highest market activity.

**Figure 1: Percent change in average trades per day relative to 2009, second week of September 2009 to 2018<sup>6</sup>**



<sup>6</sup> CME Market Depth Data, CRA analysis.

During the sample period, the average number of contracts traded daily were about 10,000 for platinum futures, 160,000 for gold futures, 235,000 for Eurodollar futures and 1,050,000 for 10-year US Treasury futures. In Figure 1 we show how the daily average contracts traded increased from 2009 levels. By 2018, platinum futures trading volume grew to 354% more than its 2009 level. Gold futures trading increased 147% more than 2009 levels, and 10-year US Treasury futures trading had grown to 65% more than 2009 levels. Eurodollars trading remained relatively consistent, with 2018 trading volume 2% lower than 2009 levels.

Using the CME market data, we also identify any new orders placed in the gold futures, platinum futures, Treasury 10-year note futures, and Eurodollar futures markets. For each market, we identify the order book updates associated with an increase in the number of orders at each price level. We only consider order book updates in which the number of orders at a price level increase by one with a corresponding increase in the number of contracts by at least one lot. Using this approach, we are able to identify new orders placed at all price levels between two consecutive updates of the order book.<sup>7</sup> There were, on average, over 150,000 new orders placed per day in the platinum futures market, nearly 700,000 new orders placed per day in the gold futures market, about 75,000 new orders placed per day in the Eurodollar futures market, and over 965,000 new orders placed per day in the 10-year US Treasury futures market.

Table 2 shows the average number of orders placed for each contract traded in each market. There are notable differences in each market; for example, in the platinum futures market, there are on average 13.8 orders placed for each contract traded; in the Eurodollar market, there are only 0.3 orders placed for each contract traded. Table 2 also shows how the average number of orders placed for each contract traded has evolved over time. While platinum and Eurodollar markets have similar ratios in 2009 and 2018, both gold and 10-year US Treasury futures had declined to about half of what they were at the start of the period.

**Table 2: Average orders per contract traded, second week of September 2009 to 2018<sup>8</sup>**

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	All Years
<b>Platinum</b>	11.50	22.13	31.73	13.22	15.75	8.11	19.99	6.89	11.63	9.69	<b>13.83</b>
<b>Gold</b>	6.19	5.85	5.70	5.23	4.09	3.93	4.05	4.11	2.84	3.56	<b>4.30</b>
<b>Eurodollar</b>	0.55	0.41	0.24	0.23	0.15	0.17	0.24	0.54	0.29	0.55	<b>0.33</b>
<b>Treasury</b>	1.21	1.13	1.42	0.64	1.08	0.78	1.10	0.89	0.54	0.52	<b>0.91</b>

We also analyze the distribution of the orders placed at different times during the trading day. For each hour during the day, we calculate the total orders placed in each product. Then, for each product, we divide the total number of orders placed in each hour by the total orders placed during the day to calculate the proportion of orders placed during the day.

<sup>7</sup> To precisely identify new orders placed in the market, one needs access to the order-level data for each trader. The publicly available CME data only shows the number of orders and the number of visible contracts aggregated across all traders in the market. The changes in the order book can be the result of the placement, modification, cancellation, and execution of orders. Absent access to order-level data for each individual trader, one can proxy the identification of new orders placed in the market in a number of ways. In this article, we assume that a new order is placed when the number of outstanding orders at a given price level increases by one and the associated order quantity increases by at least one. We use this approach because we are interested in both the number and size of new orders. Our approach ignores situations where multiple orders arrive simultaneously, or a new order arrives at the same instant that one or more existing orders is filled or canceled.

<sup>8</sup> CME Market Depth Data, CRA analysis.

**Figure 2: Proportion of new orders placed in each hour during the day, second week of September 2009 to 2018<sup>9</sup>**

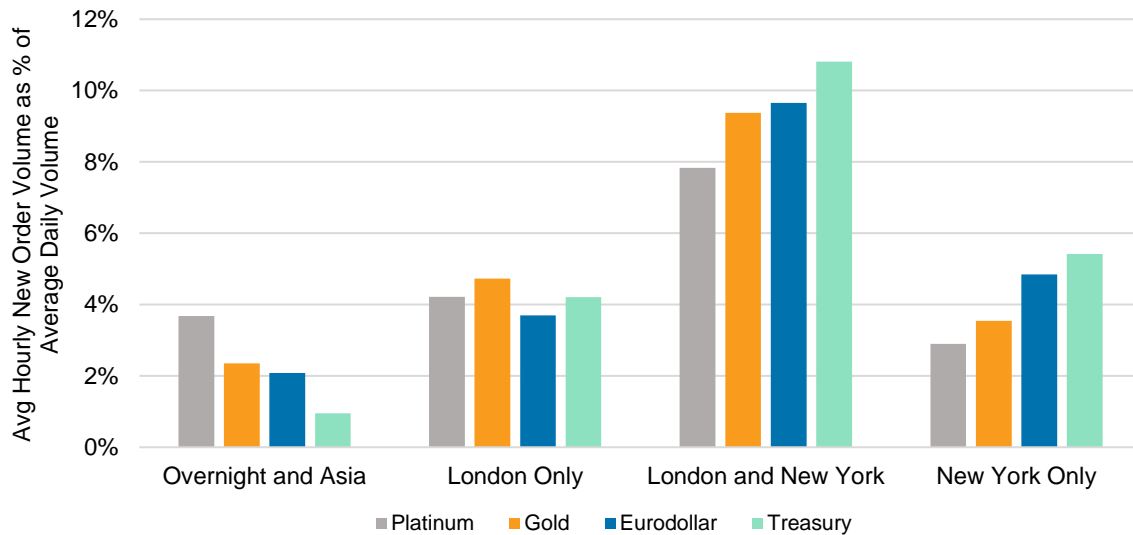


Figure 2 shows the proportion of orders placed in each hour during the day for the four products.<sup>10</sup> We divide the day into four periods: Overnight and Asia (from the 22:00 UTC market open until 07:00 UTC); London only (from 07:00 to 12:00 UTC); London and New York (from 12:00 UTC to 16:00 UTC); and New York only (from 16:00 UTC to the market close). Figure 3 shows that, across all four products, the most orders are placed during the period of time when both London and New York markets are open. While platinum futures are relatively evenly distributed across the remaining time periods, gold orders are higher during London hours, while Eurodollar and 10-year US Treasury futures orders are higher during New York hours.

### Recent spoofing allegations in futures markets

In recent years, there has been a surge in the number of cases filed by the DOJ and the CFTC on alleged spoofing-related matters. At the time of writing, the trial of James Vorley and Cedric Chanu for alleged spoofing on precious metals futures markets had started.<sup>11</sup> On August 19, 2020, the DOJ announced that the Bank of Nova Scotia had agreed to a resolution of criminal charges related to spoofing in precious metals futures.<sup>12</sup> In June 2020, the CFTC announced a settlement with Deutsche Bank in US Treasury futures and Eurodollar futures.<sup>13</sup> In 2019, the DOJ announced that two precious metals traders, Corey Flaum and Christian Trunz, pleaded guilty to

<sup>9</sup> CME Market Depth Data, CRA analysis.

<sup>10</sup> We do not report the proportion of the new orders placed during 21:00 to 22:00 UTC (16:00 to 17:00 Central Time) because all four futures markets are closed during that hour with the exception of pre-open session. Prior to September 2015, the closing times in the futures markets were at 16:15 Central Time instead of 16:00 Central Time. The pre-open session takes place for 15 minutes during the hour 21:00 to 22:00 UTC on weekdays and for the full hour on Sundays. See CME Group, CME Globex Notice: September 7, 2015, <https://www.cmegroup.com/tools-information/lookups/advisories/electronic-trading/20150907.html#dmp>, CME Group, Trading Hours: Futures & Options, <https://www.cmegroup.com/trading-hours.html#metals>; CME Group, Trading Hours: Futures & Options, <https://www.cmegroup.com/trading-hours.html#interestRates>.

<sup>11</sup> Lauraann Wood, "Feds Say Traders Exploited Market Rules In Spoofing Scheme," *Law360*, September 15, 2020, at <https://www.law360.com/articles/1310234/feds-say-traders-exploited-market-rules-in-spoofing-scheme>.

<sup>12</sup> US Department of Justice, "The Bank of Nova Scotia Agrees To Pay \$60.4 Million in Connection with Commodities Price Manipulation Scheme," Justice News, August 19, 2020, at <https://www.justice.gov/opa/pr/bank-nova-scotia-agrees-pay-604-million-connection-commodities-price-manipulation-scheme>.

<sup>13</sup> CFTC Order in the Matter of Deutsche Bank Securities, Inc., CFTC Docket No. 20-17.

price manipulation and spoofing charges.<sup>14</sup> The DOJ also indicted four individuals for alleged spoofing activity in precious metals.<sup>15</sup> In the same year, the CFTC settled with Flaum and John Edmonds for alleged spoofing in precious metals futures and settled with Benjamin Cox for alleged spoofing in E-mini S&P 500 and E-mini Nasdaq 100 futures.<sup>16</sup>

To identify alleged instances of spoofing, regulatory agencies such as the DOJ and CFTC typically look for trading patterns that they believe to be consistent with such instances e.g., where a trader executes an order on one side of the market while the same trader has a live order on the opposite side of the market. These opposite side orders are allegedly placed to provide false information about increased supply or demand to the market participants so that the orders the trader wants filled, get executed. In the plea agreements and settlements, the DOJ and the CFTC do not specify the criteria they have used to identify such instances. Instead, one has to infer the criteria from the examples provided. For instance, in the prior plea agreements and settlements, the size of the opposite-side orders was relatively large. For example, an incident involving a 245-lot order allegedly placed by Corey Flaum was referenced in the settlement with the Bank of Nova Scotia as well as the agreements with Flaum himself. At the time this order was placed, there were resting orders for just 12 lots of gold futures shown at that price level in the order book.<sup>17</sup> However, more recent settlements have also used examples of far smaller orders. The CFTC, for example, included alleged spoofing orders for just two lots of silver futures placed by Edmonds. In this example, Edmonds placed a series of 10 orders for two lots each before canceling them, for 20 lots total outstanding.<sup>18</sup> Similarly, the Trunz DOJ criminal charge included a series of eight orders for five lots each of platinum futures for 40 lots total outstanding.<sup>19</sup>

The counterparties to the alleged spoofing instances include both manual traders and algorithmic traders. Recent settlements indicate that regulators are interested in protecting both types of traders. For example, in the Bank of Nova Scotia settlement, Flaum's 245-lot alleged spoofing order was followed within one millisecond (i.e. one-one thousandth of a second) by an execution of Flaum's order on the opposite side of the market. No manual trader could plausibly react to an order within one millisecond—only an algorithmic trader's computer could react this quickly. Further, the one millisecond speed of execution suggests the algorithm was co-located on the exchange premises; algorithms located further from the exchange are not able to react to market

---

<sup>14</sup> US Department of Justice, "Precious Metals Trader Pleads Guilty to Conspiracy and Spoofing Charges," Justice News, August 20, 2019, at <https://www.justice.gov/opa/pr/precious-metals-trader-pleads-guilty-conspiracy-and-spoofing-charges>; US Department of Justice, "Former Precious Metals Trader Pleads Guilty to Attempted Commodities Price Manipulation," Justice News, July 25, 2019, at <https://www.justice.gov/opa/pr/former-precious-metals-trader-pleads-guilty-attempted-commodities-price-manipulation>.

<sup>15</sup> *United States of America v. Gregg Smith, Michael Nowak, Jeffery Ruffo, and Christopher Jordan*, US District Court Eastern District of New York, Case 1:19-cr-00669.

<sup>16</sup> CFTC Order against Corey D. Flaum, CFTC Docket No. 19-15; CFTC Order against John Edmonds, CFTC Docket No. 19-16; CFTC Order against Benjamin Cox, CFTC Docket No. 19-18.

<sup>17</sup> On December 31, 2015, at 11:40:33.666 AM Central Time, Flaum placed an order to buy 245 lots of February 2016 expiry of gold futures. CFTC Order against Corey D. Flaum, CFTC Docket No. 19-15, p. 3; *United States of America v. Corey Flaum*, US District Court Eastern District of New York, Case 1:19-cr-00338, pp. 2-3; and *United States of America v. The Bank of Nova Scotia*, US District Court for the District of New Jersey, Case 20-707 (MAS), pp. 2-3.

<sup>18</sup> On March 5, 2014, between 8:18:40.443 AM and 8:18:41.587 AM Central Time, an interval of 1.1 seconds, Edmonds placed 10 two-lot bids to buy May 2014 expiry of the Silver futures at increasing prices. CFTC Order against John Edmonds, CFTC Docket No. 19-16, p. 3.

<sup>19</sup> On June 22, 2016, beginning at approximately 2:14:35.926 AM Central Time, Trunz placed eight five-lot bids to buy platinum futures contracts. *United States of America v. Christian Trunz*, US District Court Eastern District of New York, Case 1:19-cr-00375, pp. 3-4.

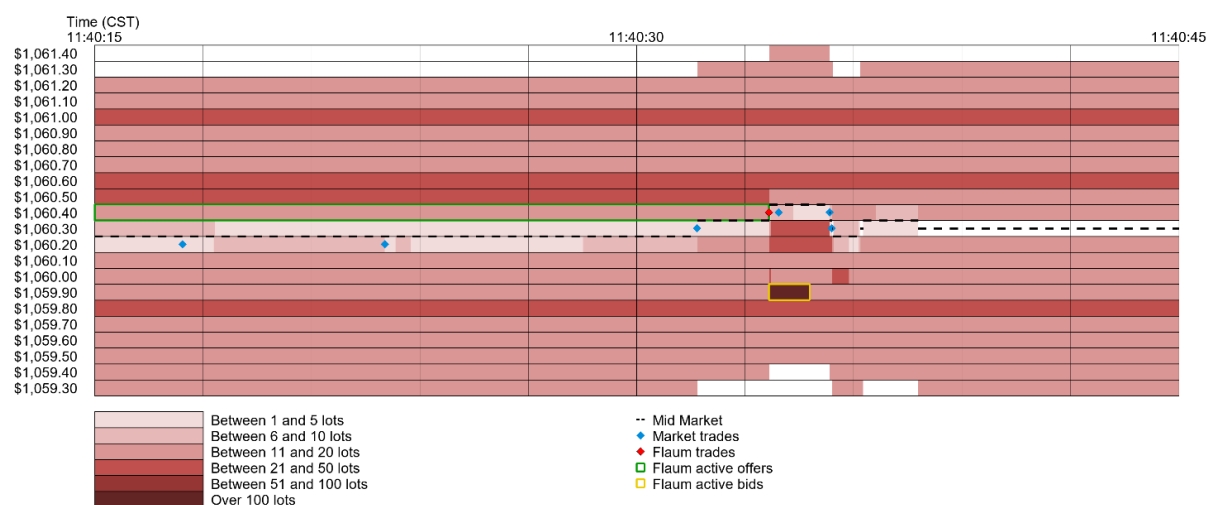
orders as quickly as co-located algorithms.<sup>20</sup> Consistent with this observation, the DOJ placed two algorithmic traders on its witness list for its case against Vorley and Chanu.<sup>21</sup>

In Figure 3, we visualize an incident from the CFTC order regarding Corey Flaum:

*On December 31, 2015 at 11:39:10.679 AM Central Time, Flaum placed an offer to sell five lots of the February 2016 expiry of the COMEX Gold Futures ... at a price of \$1,060.40, which was the best-offer level ("Genuine Gold Offer"). Approximately one minute later, at 11:40:33.666, Flaum placed an order to buy 245 lots of GCG6 at a price of \$1,059.90, which was at the fifth best bid level ("Spoofing Gold Bid"). One millisecond later, at 11:40:33.667, Flaum's Genuine Gold Offer was fully filled by other market participants. Approximately one second later, at 11:40:35.790, Flaum canceled his 245-lot Spoofing Gold Bid.<sup>22</sup>*

The horizontal axis in Figure 3 represents time; the vertical axis shows the price level of orders. The dashed line is the midpoint between the best bid and best ask. The darker the shading at any price level and at any point in time, the more lots are available at that price level. Flaum's alleged genuine order is highlighted with a green box and was placed before Figure 3 starts. The alleged spoof order is highlighted in yellow. Right after placement of the alleged spoof order, the alleged genuine order was fully filled, and then the alleged spoof order was canceled.

**Figure 3: Trading activity referenced in CFTC Order against Corey Flaum<sup>23</sup>**



<sup>20</sup> The CME's internal records would indicate whether the counterparty to Flaum's executed order was a manual or algorithmic trader along with the identity of that trader. The DOJ and CFTC would presumably have verified that the order was executed by an algorithmic trader (since a manual trader could not have been reacting to Flaum's alleged spoofing order), and that the algorithm in question was co-located at the CME. Also, prosecutors presumably would have checked the algorithmic trader's log files to verify that the algorithm was, in fact, reacting to the alleged spoof order.

<sup>21</sup> *United States of America v. James Vorley and Cedric Chanu*, US District Court Northern District of Illinois, Case 1:18-cr-00035, Government's Supplemental Memorandum in Support of Its Motion for Preliminary Admission of Co-Conspirator Statements, pp. 1-2.

<sup>22</sup> CFTC Order against Corey D. Flaum, CFTC Docket No. 19-15, p. 3.

<sup>23</sup> CME Market Depth Data, CRA analysis.



## Closing thoughts

When looking to identify potential spoofing activity, regulators have focused on futures markets. These markets are complex and have large volumes of orders placed on them during the trading day. Orders are updated rapidly, and markets can move suddenly. Isolating the actions of a single trader or group of traders among the activity of a deep group of market participants can be time consuming and complicated. CRA has extensive experience studying exchange data at the micro-/nanosecond level in order to understand an individual trader's orders in the context of broader market activity. Further, spoofing allegations can be based on communications or other evidence; careful data analysis is required to evaluate whether a trader's actual market activity is consistent with the communications and other evidence. CRA's experience and expertise provides clients with a critical resource understanding the actions of a single trader or group of traders in deep, rapidly changing futures markets.

## About the Finance Practice

CRA experts in securities and financial market issues offer collective expertise across economics, finance, accounting, and the financial industry. Companies, law firms, and government agencies rely on CRA for high-quality research and analysis, expert testimony, and comprehensive support in litigation and regulatory proceedings. Our experts include leading academics from top-tier universities, former US Securities and Exchange Commission senior staff, and financial industry practitioners. CRA experts have delivered services for a wide range of financial companies and other firms including brokers, investment banks, auditors, exchanges, clearing houses, hedge funds, private equity funds, venture capital funds, mutual fund complexes, insurance companies, and individuals. For additional information about how CRA's experts can help you with your litigation and regulatory needs, please visit: [www.crai.com/service/securities-and-financial-markets](http://www.crai.com/service/securities-and-financial-markets).

The authors would like to thank Kyle Waters for his assistance with this article.

### Contacts

**Mukarram Attari**

Vice President, Co-Practice Leader of Finance  
Oakland  
+1-510-595-2711  
[mattari@crai.com](mailto:mattari@crai.com)

**Rahul Chhabra**

Senior Associate  
Boston  
+1-617-425-3523  
[rchhabra@crai.com](mailto:rchhabra@crai.com)

**Sam Lynch**

Vice President  
Boston  
+1-617-425-3089  
[slynch@crai.com](mailto:slynch@crai.com)

**Fatih Fazilet**

Senior Associate  
Boston  
+1-617-425-3524  
[ffazilet@crai.com](mailto:ffazilet@crai.com)



The views expressed herein are the views and opinions of the authors and do not reflect or represent the views of Charles River Associates or any of the organizations with which the authors are affiliated. Any opinion expressed herein shall not amount to any form of guarantee that the authors or Charles River Associates has determined or predicted future events or circumstances, and no such reliance may be inferred or implied. The authors and Charles River Associates accept no duty of care or liability of any kind whatsoever to any party, and no responsibility for damages, if any, suffered by any party as a result of decisions made, or not made, or actions taken, or not taken, based on this paper. If you have questions or require further information regarding this issue of *CRA Insights: Finance*, please contact the contributor or editor at Charles River Associates. This material may be considered advertising. Detailed information about Charles River Associates, a registered trade name of CRA International, Inc., is available at [www.crai.com](http://www.crai.com).

Copyright 2020 Charles River Associates