ALPHACUTION

Case Study:

Two Sigma Investments, LP and Affiliates

October 2019

INTRODUCTION

HISTORY LESSON

This story starts with a review of the *second-generation* players who have grown to great fortune and notoriety by harnessing technology, human skill (via quantitative methods) and increasing amounts of data - thus applying the unprecedented technical leverage of workflow automation - to financial markets. The *first-generation* players – as detailed in the opening to Alphacution's case study on Susquehanna International Group, LLP (SIG)– was comprised of pioneers in the emerging listed derivatives market; an era that began in the late 1970's after the birth of standardized option contracts at the Chicago Board Options Exchange (CBOE) in 1973. Alphacution has designated this group as first-generation players because of their advances in workflow automation[1] primarily related to pricing and risk management in global option markets.

The second generation of quantitatively-influenced trading and investment strategies begins shortly thereafter – albeit somewhat overlapped with the first generation - with the application of mathematics and "computer-aided research" to cash equity, bond and futures markets. Here, Alphacution defines the second generation as being notable for advances in workflow automation for signal generation (including pricing and pattern recognition), equity portfolio construction (which is a critical component of risk management), and eventually in the later stages of this generation, trade execution for the cash and futures markets.

Now, with all due respect to statistical pioneer, Ed Thorp, and his Princeton/Newport Partners hedge fund founded in 1974 – who may have been the first to creatively apply mathematics to the signal generation component of a trading strategy - the subset of players that lay the groundwork for the quant revolution in equities markets and the resulting active, "statistical arbitrage" strategies begins with the founding of Renaissance Technologies, LLC by mathematician Jim Simons, in 1982 (and the subsequent launch of its Medallion Fund in 1988). As of October 28, 2019, an article in Bloomberg News credits Simons as the force behind the development of the "best hedge fund ever." However, from the same era - and pioneering a similar path with a strong focus in equities – are two additional historic forces in their own right: David Shaw, founder of D.E. Shaw & Co., Inc. in 1988, and Israel "Izzy" Englander, founder of Millennium, LP (now, Millennium Management, LLC) in 1989.

Of course, there are other notable strands to this story related to systematic trading in other products and asset classes that are worth mentioning while we are here. For instance, any walk down memory lane for the application of technology to financial markets will definitely include Bridgewater Associates, LP, founded by Ray Dalio in 1975 as a research and advisory firm, that has

[1] Alphacution defines the basic components on trade workflows as signal (or, idea) generation, trade execution, risk management and trade processing. Depending on the strategy and/or asset class, more advanced workflows can be segmented into more granular task categories, such as pre- and post-trade risk management.

since become a significant leader in the application of quantitative methods in global markets; grown to become the world's largest hedge fund (with $133 billion AUM as of year-end 2018); and, earned the distinction as the #1 hedge fund by net gains since its launch, according to Institutional Investor ("II"). However, unlike the equity-centric players mentioned above, Bridgewater's success has come more in the genre of a global macro strategy focused mainly in fixed income, currency and commodity (FICC) markets in addition to exposures in equities and equity-linked products.

Other notable managers that charted a different fork along the path to historic quantitative success, largely as systematic managed futures programs (while registered as commodity trading advisors – or, CTAs), include Mint Investments, founded by Larry Hite in 1981; AHL (originally, Adam, Harding & Lueck), founded by Michael Adam, David Harding and Martin Lueck in 1987 (which was later acquired in three stages to become Man AHL between 1989 and 1994, with Harding later moving on to found Winton Group and Adam founding Aspect Capital, both in 1997); and, Numeric Investors, founded by Lang Wheeler with its first U.S. equity strategy in 1989 (and, later, also acquired by Man Group to form Man Numeric in 2014).

And, of course, no recounting of the major players from our second generation of quantitative developments on both sides of the Atlantic would be complete without mentioning Marshall Wace, LLP, founded by Paul Marshall and Ian Wace in 1997 who - with original seeding, in part, from George Soros - apply technical innovations to support fundamental analysis for a global long/short equity portfolio on current AUM of $40 billion. AQR Capital Management (which stands for Applied Quantitative Research), co-founded by Cliff Asness and three others in 1998 also deserves mention here, with aggregate alternative and traditional AUM of $185 billion, as of Q3 2019 ($89.6 billion of which can approximately be attributed to the firm's 13F report, as of Q2 2019).

Today, in each case 30 or more years since their founding, the original second-generation triumvirate of Renaissance, D. E. Shaw and Millennium all rank in the all-time top 20 hedge fund managers, as measured by net gains since inception through 2018. Including these three, this top 20 list - published by II - contains only one more manager with a foundation in active, *alpha extraction* strategies; and, two managers that have been launched since 2000.

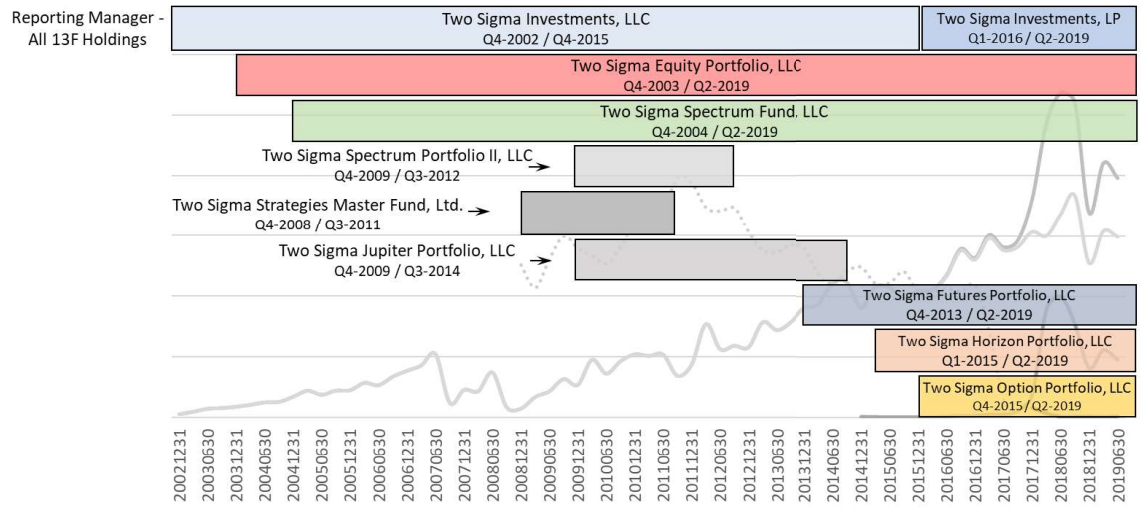
Brevan Howard Asset Management, LLP, founded in London by Alan Howard and four others in 2002 is one of the two youngest managers on the aforementioned top 20 all-time earners list. This firm gained early prominence deploying a global macro strategy which ultimately propelled AUM to a peak of $40 billion in 2013. As of the development of this case study, Alan Howard has just stepped down as CEO to focus more on trading. After significant performance challenges and AUM declines, Brevan Howard's AUM currently stands at $6.3 billion.

SONS OF D. E. SHAW

This leaves us with the youngest of the four most successful active alpha extraction players – and second youngest overall - on II's 2018 top 20 all-time net gainers list: Founded in 2001 by two former D.E. Shaw executives, mathematician John Overdeck and computer scientist David Siegel – along with a third co-founder, Mark Pickard (Tudor Investment's former chief financial officer, who retired in 2006) - **Two Sigma Investments, LP** ("Two Sigma") is arguably the last of the second-generation quant powerhouses to be established – and just as the *third-generation* players, most of them proprietary trading firms (or, "prop shops") with their highest-performance technologies and hyperactive "speed" strategies, are heating up.

What follows next is a story centered around the part of Two Sigma – the original engine and driving force behind what is now a highly diversified[2] trading (and market making), investment, advisory, technology, private equity and venture capital operation - that we can see from the available data; the regulatory "data exhaust" from the original statistical arbitrage strategy launched in April 2002. In Exhibit 1, below, Alphacution presents the US 13F reporting entities – and their timelines - that are borne out of this original strategy:

EXHIBIT 1: TWO SIGMA INVESTMENTS, LP – US 13F REPORTING ENTITIES, Q4 2002 – Q2 2019



Source: Alphacution, SEC

Note that Two Sigma is structured differently and reports differently than previous case study targets. For instance, in the cases of Citadel and Susquehanna International Group (SIG) all of the relevant trading and investment entities, including their market making arms, report 13F disclosures under a single "parent" entity. Two Sigma Investments, LP and Two Sigma Securities, LLC – its market making arm - report 13F disclosures separately. And, while the parent entity, Two

[2] Today, Two Sigma is a multi-strategy operation, exposed to risks in multiple product and asset classes, in multiple regional markets and multiple processes (which can be interpreted as a diversity in temporal trading and investment turnover frequencies). Among additional highlights, Two Sigma also has a private equity arm, Sightway Capital, LP; and, a venture capital arm, Two Sigma Ventures, LP, which is focused on innovations around data science and advanced engineering.

Sigma Investments, LP, does list five affiliated reporting managers – referenced here by the truncated names "Equity," "Spectrum," "Futures," "Horizon," and "Options" – none of these sub-entities ever designate positions separately from the parent in their filings, unlike a vast majority of the trading and investment firms Alphacution has modeled to date.

It is not clear why this variance in structure from observed norms exists as it does – nor, its significance. And, because there are no positions associated with specific sub-entities in the reporting, it is also not clear why they are disclosed at all. It does, however, imply that these entities are "closest" to the parent, and therefore, may be in place to preserve the continuity of specific strategies and provide for efficiency of administration thereafter, like the origination sources for an elaborate series of master-feeder fund structures (of which Alphacution has identified 40 specific funds). Nonetheless, the additional transparency is incrementally illuminating.

In the rest of the story that follows, and along with the recently notable and strategically-fascinating expansion of its market making arm, Two Sigma Securities, LLC (TSS), Alphacution presents its findings and analysis from the following detailed data sample:

DATA SAMPLE

The storyboards and select findings contained in this report represent Alphacution's interpretation of *Two Sigma Investments, LP*; *Two Sigma Securities, LLC* and certain affiliated entities' trading and, by implication, business strategies. The supporting data sample is comprised of the following:

- 67 quarterly 13F[3] holdings reports (including 13F-HR/A amendment reports, wherever applicable) for the nearly 17-year time range beginning December 31, 2002 (or, Q4 2002) and ending June 30, 2019 (or, Q2 2019) by the *Two Sigma Investments, LP* lineage of reporting entities;
- 19 quarterly 13F holdings reports (including 13F-HR/A amendment reports, wherever applicable) for the nearly 5-year time range beginning December 31, 2014 (or, Q4 2014) and ending June 30, 2019 (or, Q2 2019) by the *Two Sigma Securities, LLC* lineage of reporting entities;
- 43 quarterly 13F holdings reports (including 13F-HR/A amendment reports, wherever applicable) for the nearly 11-year time range beginning December 31, 2008 (or, Q4 2008) and ending June 30, 2019 (or, Q2 2019) by the *Timber Hill, LLC* lineage of reporting entities;

[3] Form 13F is a quarterly report filed, per United States Securities and Exchange Commission regulations, by "institutional investment managers" to the SEC and containing all position-level equity assets under management of at least $100 million in value with relevant long US holdings. All US-listed equity securities (including ETFs, equity options, and convertible bonds) in the manager's portfolio are included and detailed according to the issuer name, security description, the security identifier (i.e. – CUSIP number), position value, number of shares, and other attributions. As of March 31, 2019, Alphacution estimates that the full list of Form 13F securities count totals 17,707 securities. Short positions are not required to be disclosed and are not reported. Form 13F covers institutional investment managers, which include registered investment advisers (RIAs), banks, insurance companies, hedge funds, trust companies, pension funds, mutual funds, among other natural persons or entities with investment discretion over its own account or another's. Form 13F is required to be filed within 45 days of the end of a calendar quarter. Find more about the 13F dataset on the Alphacution Feed.

- 10 annual FOCUS reports (on Forms X-17A-5 and X-17A-5/A) for the years ending December 31, 2009 thru December 31, 2018 filed by *Two Sigma Securities, LLC* with the SEC, FINRA and SIPC;
- 18 annual FOCUS reports (on Forms X-17A-5 and X-17A-5/A) for the years ending December 31, 2001 thru December 31, 2018 filed by *Timber Hill, LLC* with the SEC, FINRA and SIPC;
- 11 full account reports disclosing financial and operational data for the years ending December 31, 2008 thru December 31, 2018 filed by *Two Sigma International Limited* with the United Kingdom's registrar of companies, Companies House;
- Contextual modeling, exhibits, case studies, Feed posts and/or any other pre-existing content from Alphacution's research library focusing on the evolutionary impacts of technology on global financial markets and the trading, asset management, and banking businesses they serve; and,
- Any other peripheral data or content referenced in this report that was searchable on the surface internet.

No representative of Alphacution has spoken to any representative of Two Sigma Investments, LP or affiliated entities for the preparation of this report. This report is solely based on the author's interpretation of Alphacution's ongoing assembly of raw data, contextualized modeling, and internally developed content.

CONTEXTUAL OVERVIEW

Alphacution has presented the following contextual overview in its most recent case study on SIG, however, as different subscribers and clients are entering the stream of our content development at different points in the broader chronology of that development, we thought it would be useful to repeat it here:

There are a few more concepts that we want you to be thinking about before we get into the strategy details for this case study. This is the fourth[4] in Alphacution's series of case studies where we are taking time to focus mainly on the business and trading strategies of market makers, proprietary trading firms (or, "prop shops"), and quant-focused hedge funds.

There is a reason that Alphacution is currently focusing its modeling efforts primarily – albeit, not exclusively – on those notable firms that operate in closest proximity to the sources of listed liquidity. The logic goes like this: Based on its unprecedented and unparalleled research on

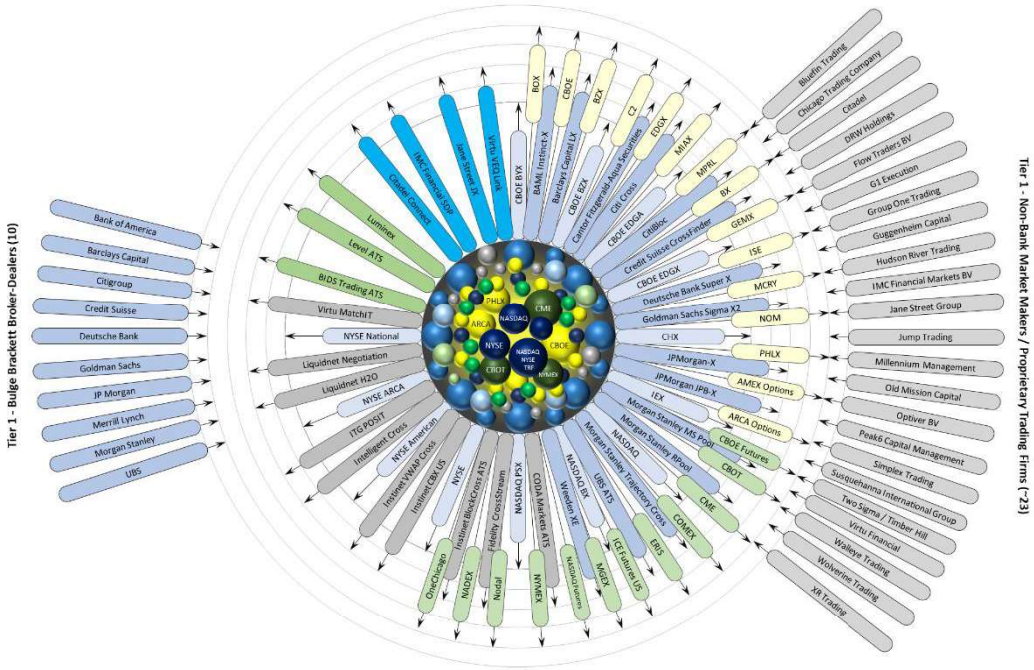
[4] The subjects of the first three case studies were Spot Trading, the Chicago-based proprietary options trading firm that closed in late 2017; Citadel Securities, the Chicago-headquartered equity, exchange-traded funds (ETFs) and options market making powerhouse – and, perhaps more famously, an affiliate of the Citadel hedge fund operation; and, the aforementioned SIG, including primarily its market making arms Susquehanna Securities and G1 Execution Services.

technology spending patterns in trading and asset management and the subset of those firms that successfully wield technology to the point of competitive advantage, Alphacution believes that the entire asset management ecosystem – of which market making and proprietary trading are a unique part – is being bifurcated between *alpha investment vehicles* and *beta investment vehicles*. Alphacution's research has further highlighted the concept that alpha – or, "outperformance" – has finite capacity. This means that there is a limited amount of capital upon which an *excess rate of return* can be earned. Furthermore, beyond the capacity level of capital to capture alpha, rates of return will decline until they reach the market rate of return – or, beta.

So, if the capacity of outperformance is finite and those who wield "industrialized" technical capabilities are best positioned to harvest that capacity, then market participants should definitely want to understand who these tech-wielding players are and try to quantify how much "alpha capacity" they are capturing. Most importantly, our concern is that a vast majority of the capacity of alpha is at risk of being "privatized" within leading market making, "prop" and hedge fund firms, thereby leaving only beta, *beta-surrogates*, and *alpha-imposters* accessible by the rest of us.

Showcasing this hypothesis and related market ecosystem dynamics is the goal of Alphacution's current series of case studies. In Exhibit 2, below, Alphacution presents its initial list of the top 100 players in US listed markets (first published in February 2019). Note that we will draw the subjects of upcoming case studies from this list – and those closely tied this list - for the foreseeable future.

EXHIBIT 2: TOP 100 PLAYERS IN US LISTED MARKET STRUCTURE (V1.0) – ALPHACUTION'S "STRUCTURAL ALPHA ZONE"



Source: Alphacution, SEC, FINRA, company data

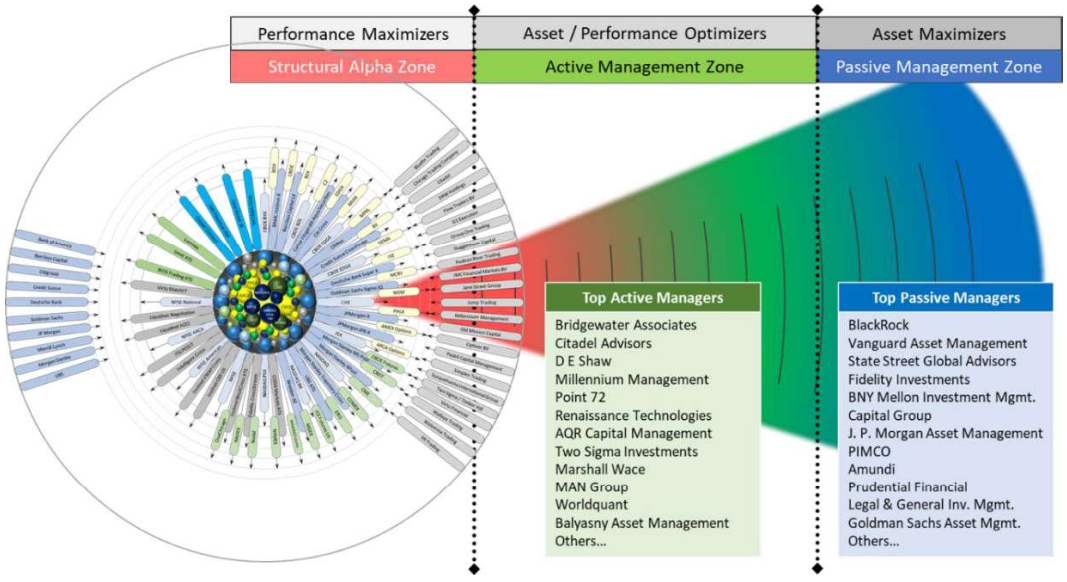
This community of market makers and prop shops populate what Alphacution calls the *structural alpha zone*. These are the "performance maximizers" that deploy the most sophisticated technical

infrastructure on the least amount of capital to harvest the greatest risk-adjusted returns based on complex nuances of *market microstructures*. These structural players operate on a segment of a much broader continuum of trading and investment strategies that Alphacution has designated as three zones that are segmented largely on the basis of average position holding duration (or, average strategy turnover frequency – ToF).

In time, Alphacution will refine this structural list by ranking the players based on its modeling of empirical evidence. That exercise is ongoing. However, in the interim, our structural alpha zone target list is comprised entirely of trading firms that simultaneously disclose certain holdings via 13F reports and are registered as broker-dealers. This unique level of transparency into risk-taking operations helps us harvest greater insights from the available data. Moreover, the most fascinating subset of this target list 1) represent components of broader multi-strategy / multi-ToF trading platforms, like the affiliated duos Citadel Securities - Citadel Advisors, Two Sigma Securities - Two Sigma Investments, or Latour Trading – Tower Research Capital; and/or 2) are making markets across multiple product classes, like cash, derivatives and/or structured products (namely, ETFs). Because it is here – among those who are proficient in options and other complex product trading – that our experience tells us that both technical and computational leadership is most likely to occur.

Adjacent to the structural alpha zone is the *active management zone* where a vast majority of hedge funds deploying various relative-value strategies and seeking a balance of assets under management (AUM) and performance reside. As AUM increases beyond the capacities of relative-value strategies, we arrive at the *passive management zone* where most traditional asset managers and a few massive ETF issuers reside. Exhibit 3 is Alphacution's visualization of the three zones that make up its asset management ecosystem map with a (currently subjective) selection of top managers for each zone.

EXHIBIT 3: ASSET MANAGEMENT ECOSYSTEM MAP WITH LIQUIDITY POOLS (V1.1)



Source: Alphacution, SEC, FINRA, company data

Now, with all this painstaking setup serving as stage and backdrop, we are just about ready to head into the details on Two Sigma. However, there's one last contextual exercise we need to perform before we go there:

COMPETITIVE INTELLIGENCE

Why is this research important?

For hardcore students of the game, the puzzle-solving aspect of research like this is a reward in and of itself. For others, there is an entertainment value to the act of telling stories that demystify the historically mysterious, particularly in cases where massive wealth accumulation has occurred. But, for most of us, there needs to be a practical value to spending precious time with this content. In other words, how do I accumulate (or save) money and attract talent with this information?

This research is designed to provide *competitive intelligence* to mature, leading and aspiring participants and their stakeholders within the global asset management ecosystem to develop better trading and business strategies. Alphacution's Feed currently provides snippets, samples and "teasers" from this research effort, while the case studies provide deeper and more comprehensive analysis for premium content subscribers.

Within the case studies, there are two parallel objectives. The first objective is to leverage the underlying data to frame the basic parameters of one or more firms' trading strategies and portfolio construction techniques as accurately and in as much detail as possible. The second objective is focused on learning how to assemble, visualize and interpret the data in ever more creative, yet consumable, ways to expand our understanding of the subject of the study.

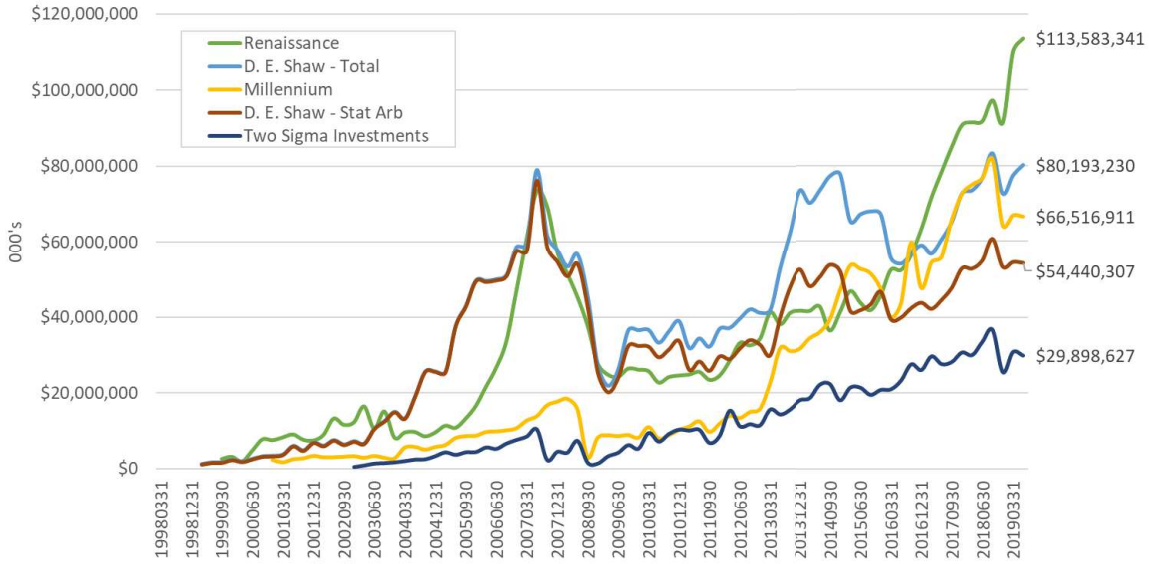
Since no one has ever assembled, visualized and interpreted the available data out in the open like this before - and the underlying mechanics of highly automated, high speed and/or multi-product trading strategies are complex and often unfamiliar to many in our network - there is a significant amount of experimentation that goes into the development of this output. And, where experimentation is ongoing, inevitably, mistakes and misinterpretations are going to occur. Ideally, our interpretations improve with more data, modeling and analysis.

This is where you – our readers – bear some responsibility to harvest the most intelligence from this work. Alphacution is committed to presenting the data in highly visual formats because that is the most efficient way to translate and consume significant amounts of information. In the end, much of this exercise comes down to interpreting "shapes," – the wiggly lines, trajectories, spikes and other anomalous shapes formed by the data – to best inform our readers. Though our interpretations may not always be the most accurate for every circumstance or the most relevant for every reader, our attempts at interpretation are intended to educate as much as they are

meant to explain. Consumers of this research are advised to learn how to "read" the shapes presented herein for their own purposes.

Here's an example of learning to interpret: In Exhibit 4, below, Alphacution presents ranking of 13F gross notional (long) market values for Two Sigma and its closest peer group, including D. E. Shaw (both total and stat arb carveout), Millennium and Renaissance for each of their total filing periods.

EXHIBIT 4: SELECT BUY-SIDE RANKING OF 13F GROSS NOTIONAL (LONG) MARKET VALUES, Q1 1998 – Q2 2019



Source: Alphacution, SEC

Notice the spikes, variances, levels, rank order and trajectories. Each of these twists, both individually and contextually, mean something. By this measure, notice how Two Sigma's track record appears to be the most consistent among these peers. Two Sigma appears to be scaling this book of exposures more methodically than the rest. This not only requires discipline in portfolio scaling, it also requires discipline in fundraising, as well.

The point being: With this research, ***shapes come first***. Keep this in mind as you review the material below. We will continue to point out opportunities for interpretation and the occasional illusion, whenever relevant.

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ABOUT ALPHACUTION

Alphacution is in the *intelligence* business.

Founded by market veteran Paul Rowady, Alphacution Research Conservatory LLC ("Alphacution") is the first digitally oriented research and strategic advisory platform uniquely focused on measuring, modeling and benchmarking the evolutionary impacts of technology on global financial markets and the trading, asset management, and banking businesses they serve. Based on an expanding research library focused on the modeling of specific market actors, composited industry segments, and key thematic drivers, the Alphacution platform is specifically designed to deliver data-driven and quantitatively based intelligence to a forward-thinking network of market participants and their stakeholders.

AUTHOR PAUL ROWADY

Paul Rowady is the Founder and Director of Research for Alphacution Research Conservatory and a 30-year veteran of proprietary, hedge fund and capital markets research, trading and risk advisory initiatives. Paul has earned an extremely unique spectrum of expertise across a range of fundamental and quantitative strategy research methods, derivatives trading, risk management, and techno-operational developments including process re-engineering and workflow automation. Prior to founding Alphacution, he was the founding principal of TABB Group's technology, analytics, and data advisory practice. Paul has also held senior roles with firms like O'Connor & Associates – as Research Analyst and Portfolio Manager; Quantlab Financial – as Co-Founder, Head of Trading and Risk; and, Ritchie Capital Management – as a Managing Director, Head of Research. Paul earned a Master of Management from the J. L. Kellogg Graduate School of Management at Northwestern University. He was also awarded a patent related to an event-driven trading analysis and volatility prediction interface and system in 2009.

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