The Life Aquatic

Deeper depth in the Treasury market microstructure

- The rapid withdrawal of HFT in March contributed significantly to the spike in intra and inter-day volatility
- Although markets have recovered, fragility in market depth is an acute concern going forward, particularly in light of the connection to Fed interventions
- In particular, liquidity has still not returned to 'normal' at the ultra-long end of the curve and bears watching as Treasury contemplates more coupon supply in late-20 and 2021
- Whereas our previous work has focused on the closest positions in the order book to the market mid, we widen the lens here to observe the contours of depth as move along the queue…
- … this data helps show the extent to which HFTs remove themselves from the market altogether during large vol spikes, versus moving back in the queue for more moderate ones
- The breadth of the order book has gradually improved and appears far less volatile now than several years ago

US Fixed Income Strategy

Henry St John AC
(1-212) 834-5669
henry.stjohn@jpmorgan.com

Joshua Younger
(1-212) 270-1323
joshua.d.younger@jpmorgan.com

Sejal Aggarwal
(1-212) 834-5116
sejal.aggarwal@jpmchase.com

J.P. Morgan Securities LLC

See page 6 for analyst certification and important disclosures.
J.P. Morgan does and seeks to do business with companies covered in its research reports. As a result, investors should be aware that the firm may have a conflict of interest that could affect the objectivity of this report. Investors should consider this report as only a single factor in making their investment decision.

This document is being provided for the exclusive use of CHRISTOPHER Lee at JPMorgan Chase & Co. and clients of J.P. Morgan.

Joshua Younger
(1-212) 270-1323
joshua.d.younger@jpmorgan.com

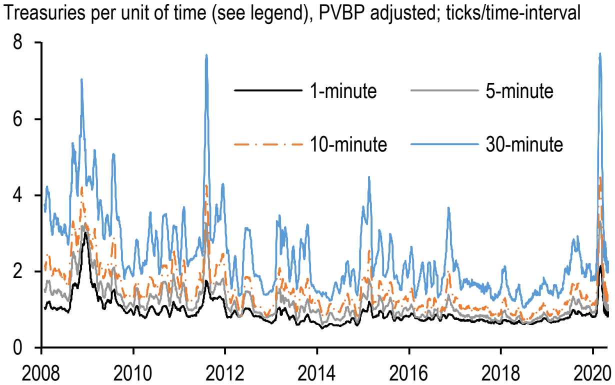
Henry St John
(1-212) 834-5669
henry.stjohn@jpmorgan.com

The Life Aquatic

Much of our recent work on market structure has focused on the role of high frequency traders (HFTs) in contributing to market depth in the central limit order book. Over the past few years, their role as market makers has become a cornerstone of fixed income market functioning—increasing from 35% of liquidity provision in the aftermath of the 2008 crisis, to 65% in 2015, and more than 76%, on average, in the two months preceding the COVID-19 market panic. **Their rapid withdrawal from market making contributed significantly to the spike in volatility during March, including some evidence of short-lived but violent price action evoking the events of October 15, 2014** (see *Did US rates markets just experience a mini "flash rally"?*, J. Younger & H. St John, 3/7/20). As a result, their contribution to the depth of the order book is a key component of our index of fixed income market functioning (see *Almost back to 'normal'*, J. Younger & H. St John, 4/14/20).

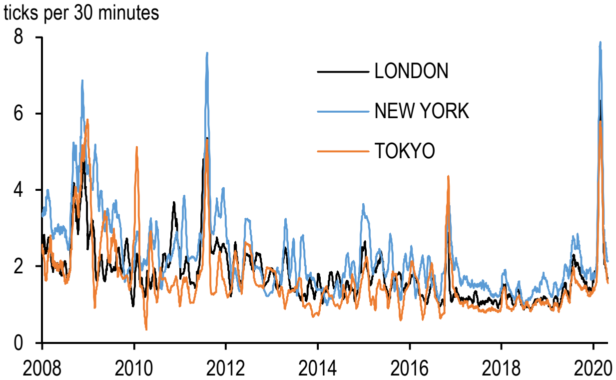
This fragility is an acute concern going forward, particularly in light of the connection between Fed interventions and these measures of market functioning. It also remains notable that HFT activity, and liquidity in general, has still not returned to 'normal' at the ultra-long end the curve (see *Wild at Heart*, H. St John et al., 4/30/20), and this is also true of more top-down level indicators, such as RMSE and dealer positions (see Treasuries*: After the flood*, J. Barry et al., 5/8/20). As the Treasury begins to lean more heavily on longer maturities to fund the widest budget deficit relative to the size of the economy since the Second World War, including a newly relaunched 20-year benchmark, these microstructure considerations are an important consideration for the join agencies who oversee the Treasury market, as a robust and healthy Treasury market ensures smooth and stable functioning of financial markets.

Exhibit 1: Intraday price volatility spiked in mid-March, in some instances reaching all-time highs …
Price volatility in the Volume Weighted Mid Price (VWMP) for US 10-year Treasuries per unit of time (see legend), PVBP adjusted; ticks/time-interval



Source: J.P. Morgan, BrokerTec

Exhibit 2: … and it was also notable that price action was most disorderly during the New York session
Rolling 2-week order book VWMP volatility for 10-year Treasuries, PVBP adjusted; ticks per 30 minutes



Source: J.P. Morgan, BrokerTec

The extent of the breakdown in market structure in the first few weeks of March can scarcely be understated. One way to highlight this is by focusing on intraday volatility on incrementally small time-scales on the passive side of the market. The average volume weighted mid-price (VWMP) per minute for 10s was at its highest level since 2008, and average volatility in the VWMP per 5 minutes actually reached its highest level on record this past March (**Exhibit 1**). **An interesting characteristic of this order-book price volatility is that the spikes**

This document is being provided for the exclusive use of CHRISTOPHER Lee at JPMorgan Chase & Co. and clients of J.P. Morgan.

Joshua Younger
(1-212) 270-1323
joshua.d.younger@jpmorgan.com

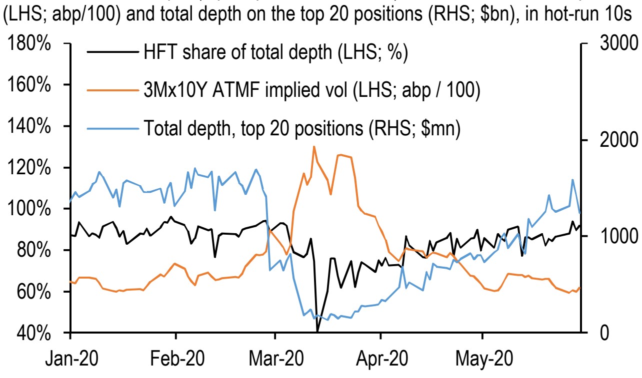
Henry St John
(1-212) 834-5669
henry.stjohn@jpmorgan.com

were highest during the New York trading session. Even more striking, this high-frequency volatility was at its peak during New York trading, when liquidity is typically at peak for a typical day: in March, VWMP volatility was 6.5 ticks/30-minutes during New York trading hours, compared to 5.2 ticks and 4.9 ticks/30-minutes for London and Tokyo, respectively (**Exhibit 2**). Though we saw comparable price action in prior crises—including the fall of 2008 and summer of 2011—increased reliance on HFT activity meant that market microstructure was more brittle with respect to very short-term volatility than during those prior episodes.

We have made this point before, of course (see Interest Rate Derivatives, *US Fixed Income Markets Weekly*, 4/17/20). But so far, our analysis of market depth has tended to focus on the most active region of the order book—i.e., prices closest to the traded level. When we refer to HFT participation, it often relates to their share at the best three prices on the bid and ask side of the stack. **However important these positions are to price discovery, they represent a relatively small fraction of total liquidity provision at any given time**: for example, on average in recent years the top 10 and 15 positions on both sides tend to represent approximately 50% and 82% of the market in 10s, respectively. **In focusing on just the most active region of the order book, what might be missed is the extent to which HFT participants tend to reposition themselves in the queue, rather than retreating from the market altogether.** This can carry significant implications for overall liquidity conditions: in one case, HFTs respond to elevated volatility in quantity space, reducing total depth across the entire order book, in the other, they are still willing to supply liquidity to the market, but at wider prices relative to market mid.

Exhibit 3: Total depth across the top 20 positions on both sides of the market dropped significantly in March, consistent with HFTs dissipating from the market altogether…

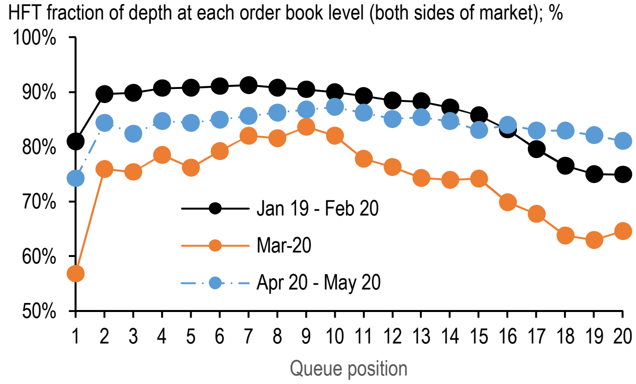
HFT share of total depth (top 20 positions, LHS; %) and 3Mx10Y ATMF implied vol (LHS; abp/100) and total depth on the top 20 positions (RHS; $bn), in hot-run 10s



Source: J.P. Morgan, BrokerTec

Exhibit 4: … While this effect was acute closest to the front price, it was felt all the way along the stack

HFT fraction of depth at each order book level (both sides of market); %



Source: J.P. Morgan, BrokerTec

Evidence suggests that a large share of HFTs withdrew completely from the market in March. Total depth at the top 20 levels on both sides of the market collapsed, with a fairly staggering peak-to-trough decline of 92%. The HFT fraction of this far larger slice of the order book similarly collapsed, falling to as low as 41% in late March, from an average level of 88% over the previous year (**Exhibit 3**). As we noted in our analysis of the new 20-year Treasury, **the structure of HFT participation along the order book stack in 10s is remarkably stable**. The share tends to peak out around the 2nd-4th positions in the queue, on average, during low volatility periods, but with a very gradual tailing off as you move further from the market mid (**Exhibit 4**). In March, the curve did "steepen" somewhat, with the share

This document is being provided for the exclusive use of CHRISTOPHER Lee at JPMorgan Chase & Co. and clients of J.P. Morgan.

Joshua Younger
(1-212) 270-1323
joshua.d.younger@jpmorgan.com

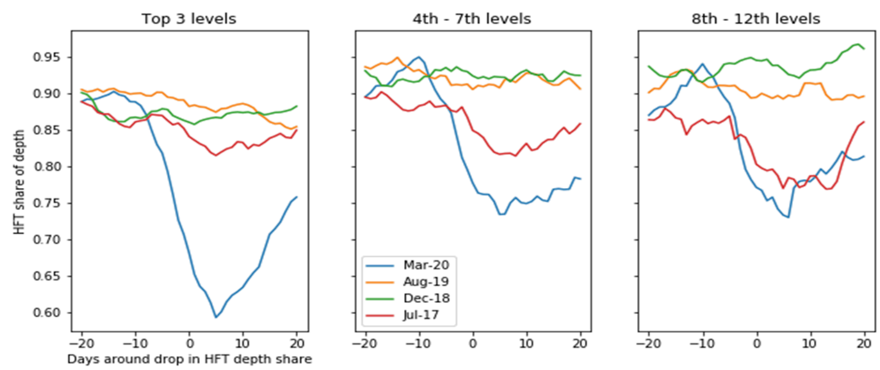
Henry St John
(1-212) 834-5669
henry.stjohn@jpmorgan.com

of HFT participation dropping most precipitously at the front of the queue than the back, consistent with these participants moving their orders to reflect a fatter-tailed distribution of expected price outcomes.

Was the experience of March different from prior volatile episodes? Looking back over the past few years, **we find only partial evidence at best to suggest that HFT participation repositions down the stack, rather than withdraws entirely**. In other words, when volatility rises, HFTs tend to reduce their activity altogether. In the cases of year-end 2018 and the drop-off in liquidity in late summer of last year, we did see stability, and in some cases improvement, in HFT participation further out the order book (**Exhibit 5**). More generally, correlation of HFT participation across different segments of the order book tends to rise as volatility rises, but is almost always in positive territory (**Exhibit 6**).

Exhibit 5: We see some evidence that for smaller deteriorations in liquidity, HFT participation further back in the queue rises modestly

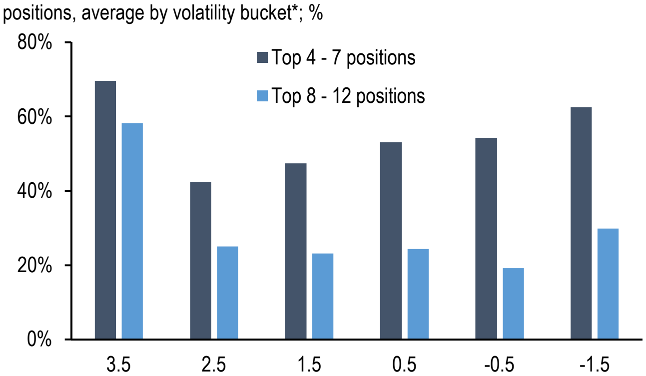
Fraction of total depth at each queue position around recent periods in which HFT share of depth has declined; %



Source: J.P. Morgan, BrokerTec

Exhibit 6: More generally, HFT participation across the queue tends to become more positively correlated as vol rises

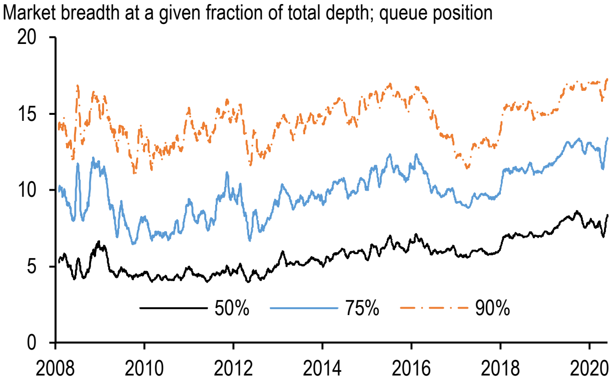
Correlation of HFT share of queue positions with the HFT share of the top 3 queue positions, average by volatility bucket*; %



Note: Vol buckets defined as the standardized intraday realized order book volatility during the New York session. See Exhibit 2 for detail.
Source: J.P. Morgan, BrokerTec

Exhibit 7: The breadth of the order book has gradually increased over time, suggesting depth is more dispersed away from the mid-price

Market breadth at a given fraction of total depth; queue position



Note: Queue position at which this percentage of total depth is reached. E.g. on average, 90% of total depth is cumulatively filled at the 15th position.
Source: J.P. Morgan, BrokerTec

One complementary characteristic to note is that the breadth of the order book appears to have trended steadily higher for several years now. We find that the number of positions it takes to reach 90% of total depth on both sides of the order book is now around 16, an all-time high (**Exhibit 7**). This breadth appears to be

This document is being provided for the exclusive use of CHRISTOPHER Lee at JPMorgan Chase & Co. and clients of J.P. Morgan.

Joshua Younger
(1-212) 270-1323
joshua.d.younger@jpmorgan.com

Henry St John
(1-212) 834-5669
henry.stjohn@jpmorgan.com

notably consistent when we move down to smaller fractions of total depth, suggesting the build-out in depth across queue positions has been fairly stable in 10s, consistent with the steady fraction of HFT participation at these latter queue positions as well. It tends to be the case also that during periods in which liquidity has become temporarily impaired over the last decade, the breadth of the order book has tended to widen, meaning that a greater share of total order book volume has been pushed back on average 1-2 positions.

What are we to conclude from this exercise? In March, **increased reliance on HFT liquidity provision has once again proven to be an accelerant for disorderly price action**—this is neither surprising nor a new observation. What is notable is the extent to which they pulled back across the stack, rather than simply repositioning to reflect higher levels of intraday volatility. Though this was more acute in March than other recent episodes, it appears to be a rather uniform reaction to stressed market conditions. If anything the recent experience could cause some of those HFT participants to reduce their tolerance for intraday volatility, particularly if volumes are relatively light as well. Thus, while liquidity appears to have improved along a range of indicators, we believe it remains quite brittle.

This document is being provided for the exclusive use of CHRISTOPHER Lee at JPMorgan Chase & Co. and clients of J.P. Morgan.

Joshua Younger
(1-212) 270-1323
joshua.d.younger@jpmorgan.com

Henry St John
(1-212) 834-5669
henry.stjohn@jpmorgan.com

Analyst Certification: The research analyst(s) denoted by an "AC" on the cover of this report certifies (or, where multiple research analysts are primarily responsible for this report, the research analyst denoted by an "AC" on the cover or within the document individually certifies, with respect to each security or issuer that the research analyst covers in this research) that: (1) all of the views expressed in this report accurately reflect the research analyst's personal views about any and all of the subject securities or issuers; and (2) no part of any of the research analyst's compensation was, is, or will be directly or indirectly related to the specific recommendations or views expressed by the research analyst(s) in this report. For all Korea-based research analysts listed on the front cover, if applicable, they also certify, as per KOFIA requirements, that their analysis was made in good faith and that the views reflect their own opinion, without undue influence or intervention.

All authors named within this report are research analysts unless otherwise specified. In Europe, Sector Specialists may be shown on this report as contacts but are not authors of the report or part of the Research Department.

Important Disclosures

Company-Specific Disclosures: Important disclosures, including price charts and credit opinion history tables, are available for compendium reports and all J.P. Morgan–covered companies by visiting https://www.jpmm.com/research/disclosures, calling 1-800-477-0406, or e-mailing research.disclosure.inquiries@jpmorgan.com with your request. J.P. Morgan's Strategy, Technical, and Quantitative Research teams may screen companies not covered by J.P. Morgan. For important disclosures for these companies, please call 1-800-477-0406 or e-mail research.disclosure.inquiries@jpmorgan.com.

Analysts' Compensation: The research analysts responsible for the preparation of this report receive compensation based upon various factors, including the quality and accuracy of research, client feedback, competitive factors, and overall firm revenues.

Other Disclosures

J.P. Morgan is a marketing name for investment banking businesses of JPMorgan Chase & Co. and its subsidiaries and affiliates worldwide.

Any data discrepancies in this report could be the result of different calculations and/or adjustments.

Any long form nomenclature for references to China; Hong Kong; Taiwan; and Macau within this research report are Mainland China; Hong Kong SAR, China; Taiwan, China; Macau SAR, China.

Options and Futures related research: If the information contained herein regards options or futures related research, such information is available only to persons who have received the proper options or futures risk disclosure documents. Please contact your J.P. Morgan Representative or visit https://www.theocc.com/components/docs/riskstoc.pdf for a copy of the Option Clearing Corporation's Characteristics and Risks of Standardized Options or http://www.finra.org/sites/default/files/Security_Futures_Risk_Disclosure_Statement_2018.pdf for a copy of the Security Futures Risk Disclosure Statement.

Changes to Interbank Offered Rates (IBORs) and other benchmark rates: Certain interest rate benchmarks are, or may in the future become, subject to ongoing international, national and other regulatory guidance, reform and proposals for reform. For more information, please consult: https://www.jpmorgan.com/global/disclosures/interbank_offered_rates

Principal Trading: J.P. Morgan trades or may trade as principal in the derivatives or the debt securities (or related derivatives) that are the subject of this report.

Private Bank Clients: Where you are receiving research as a client of the private banking businesses offered by JPMorgan Chase & Co. and its subsidiaries ("J.P. Morgan Private Bank"), research is provided to you by J.P. Morgan Private Bank and not by any other division of J.P. Morgan, including but not limited to the J.P. Morgan corporate and investment bank and its research division.

Legal entity responsible for the production of research: The legal entity identified below the name of the Reg AC research analyst who authored this report is the legal entity responsible for the production of this research. Where multiple Reg AC research analysts authored this report with different legal entities identified below their names, these legal entities are jointly responsible for the production of this research.

Legal Entities Disclosures
U.S.: JPMS is a member of NYSE, FINRA, SIPC and the NFA. JPMorgan Chase Bank, N.A. is a member of FDIC. **Canada**: J.P. Morgan Securities Canada Inc. is a registered investment dealer, regulated by the Investment Industry Regulatory Organization of Canada and the Ontario Securities Commission and is the participating member on Canadian exchanges. **U.K.**: JPMorgan Chase N.A., London Branch, is authorised by the Prudential Regulation Authority and is subject to regulation by the Financial Conduct Authority and to limited regulation by the Prudential Regulation Authority. Details about the extent of our regulation by the Prudential Regulation Authority are available from J.P. Morgan on request. J.P. Morgan Securities plc (JPMS plc) is a member of the London Stock Exchange and is authorised by the Prudential Regulation Authority and regulated by the Financial Conduct Authority and the Prudential Regulation Authority. Registered in England & Wales No. 2711006. Registered Office 25 Bank Street, London, E14 5JP. **Germany**: This material is distributed in Germany by J.P. Morgan Securities plc, Frankfurt Branch which is regulated by the Bundesanstalt für Finanzdienstleistungsaufsich and also by J.P. Morgan AG (JPM AG) which is a member of the Frankfurt stock exchange and is regulated by the Federal Financial Supervisory Authority (BaFin), JPM AG is a company incorporated in the Federal Republic of Germany with registered office at Taunustor 1, 60310 Frankfurt am Main, the Federal Republic of Germany. **South Africa**: J.P. Morgan Equities South Africa Proprietary Limited is a member of the

This document is being provided for the exclusive use of CHRISTOPHER Lee at JPMorgan Chase & Co. and clients of J.P. Morgan.

Joshua Younger
(1-212) 270-1323
joshua.d.younger@jpmorgan.com

Henry St John
(1-212) 834-5669
henry.stjohn@jpmorgan.com

Johannesburg Securities Exchange and is regulated by the Financial Services Board. **Hong Kong**: J.P. Morgan Securities (Asia Pacific) Limited (CE number AAJ321) is regulated by the Hong Kong Monetary Authority and the Securities and Futures Commission in Hong Kong and/or J.P. Morgan Broking (Hong Kong) Limited (CE number AAB027) is regulated by the Securities and Futures Commission in Hong Kong. JP Morgan Chase Bank, N.A., Hong Kong is organized under the laws of U.S.A. with limited liability. **China**: J.P. Morgan Securities (China) Company Limited has been approved by CSRC to conduct the securities investment consultancy business. **Korea**: This material is issued and distributed in Korea by or through J.P. Morgan Securities (Far East) Limited, Seoul Branch, which is a member of the Korea Exchange(KRX) and is regulated by the Financial Services Commission (FSC) and the Financial Supervisory Service (FSS). **Australia**: J.P. Morgan Securities Australia Limited (JPMSAL) (ABN 61 003 245 234/AFS Licence No: 238066) is regulated by ASIC and is a Market, Clearing and Settlement Participant of ASX Limited and CHI-X. **Taiwan**: J.P. Morgan Securities (Taiwan) Limited is a participant of the Taiwan Stock Exchange (company-type) and regulated by the Taiwan Securities and Futures Bureau. **India:** J.P. Morgan India Private Limited (Corporate Identity Number - U67120MH1992FTC068724), having its registered office at J.P. Morgan Tower, Off. C.S.T. Road, Kalina, Santacruz - East, Mumbai – 400098, is registered with Securities and Exchange Board of India (SEBI) as a 'Research Analyst' having registration number INH000001873. J.P. Morgan India Private Limited is also registered with SEBI as a member of the National Stock Exchange of India Limited and the Bombay Stock Exchange Limited (SEBI Registration Number – INZ000239730) and as a Merchant Banker (SEBI Registration Number - MB/INM000002970). Telephone: 91-22-6157 3000, Facsimile: 91-22-6157 3990 and Website: www.jpmipl.com. For non local research reports, this material is not distributed in India by J.P. Morgan India Private Limited. **Thailand**: This material is issued and distributed in Thailand by JPMorgan Securities (Thailand) Ltd., which is a member of the Stock Exchange of Thailand and is regulated by the Ministry of Finance and the Securities and Exchange Commission and its registered address is 3rd Floor, 20 North Sathorn Road, Silom, Bangrak, Bangkok 10500. **Indonesia**: PT J.P. Morgan Sekuritas Indonesia is a member of the Indonesia Stock Exchange and is regulated by the OJK a.k.a. BAPEPAM LK. **Philippines**: J.P. Morgan Securities Philippines Inc. is a Trading Participant of the Philippine Stock Exchange and a member of the Securities Clearing Corporation of the Philippines and the Securities Investor Protection Fund. It is regulated by the Securities and Exchange Commission. **Brazil**: Banco J.P. Morgan S.A. is regulated by the Comissao de Valores Mobiliarios (CVM) and by the Central Bank of Brazil. **Mexico**: J.P. Morgan Casa de Bolsa, S.A. de C.V., J.P. Morgan Grupo Financiero is a member of the Mexican Stock Exchange and authorized to act as a broker dealer by the National Banking and Securities Exchange Commission. **Singapore:** This material is issued and distributed in Singapore by or through J.P. Morgan Securities Singapore Private Limited (JPMSS) [MCI (P) 018/04/2020 and Co. Reg. No.: 199405335R], which is a member of the Singapore Exchange Securities Trading Limited and/or JPMorgan Chase Bank, N.A., Singapore branch (JPMCB Singapore) [MCI (P) 070/09/2019], both of which are regulated by the Monetary Authority of Singapore. This material is issued and distributed in Singapore only to accredited investors, expert investors and institutional investors, as defined in Section 4A of the Securities and Futures Act, Cap. 289 (SFA). This material is not intended to be issued or distributed to any retail investors or any other investors that do not fall into the classes of "accredited investors," "expert investors" or "institutional investors," as defined under Section 4A of the SFA. Recipients of this document are to contact JPMSS or JPMCB Singapore in respect of any matters arising from, or in connection with, the document. **Japan**: JPMorgan Securities Japan Co., Ltd. and JPMorgan Chase Bank, N.A., Tokyo Branch are regulated by the Financial Services Agency in Japan. **Malaysia**: This material is issued and distributed in Malaysia by JPMorgan Securities (Malaysia) Sdn Bhd (18146-X) which is a Participating Organization of Bursa Malaysia Berhad and a holder of Capital Markets Services License issued by the Securities Commission in Malaysia. **Pakistan**: J. P. Morgan Pakistan Broking (Pvt.) Ltd is a member of the Karachi Stock Exchange and regulated by the Securities and Exchange Commission of Pakistan. **Dubai**: JPMorgan Chase Bank, N.A., Dubai Branch is regulated by the Dubai Financial Services Authority (DFSA) and its registered address is Dubai International Financial Centre - Building 3, Level 7, PO Box 506551, Dubai, UAE. **Russia:** CB J.P. Morgan Bank International LLC is regulated by the Central Bank of Russia. **Argentina:** JPMorgan Chase Bank Sucursal Buenos Aires is regulated by Banco Central de la República Argentina ("BCRA"- Central Bank of Argentina) and Comisión Nacional de Valores ("CNV"- Argentinian Securities Commission")

Country and Region Specific Disclosures
U.K. and European Economic Area (EEA): Unless specified to the contrary, issued and approved for distribution in the U.K. and the EEA by JPMS plc. Investment research issued by JPMS plc has been prepared in accordance with JPMS plc's policies for managing conflicts of interest arising as a result of publication and distribution of investment research. Many European regulators require a firm to establish, implement and maintain such a policy. Further information about J.P. Morgan's conflict of interest policy and a description of the effective internal organisations and administrative arrangements set up for the prevention and avoidance of conflicts of interest is set out at the following link https://www.jpmorgan.com/jpmpdf/1320742677360.pdf. This report has been issued in the U.K. only to persons of a kind described in Article 19 (5), 38, 47 and 49 of the Financial Services and Markets Act 2000 (Financial Promotion) Order 2005 (all such persons being referred to as "relevant persons"). This document must not be acted on or relied on by persons who are not relevant persons. Any investment or investment activity to which this document relates is only available to relevant persons and will be engaged in only with relevant persons. In other EEA countries, the report has been issued to persons regarded as professional investors (or equivalent) in their home jurisdiction. **Australia:** This material is issued and distributed by JPMSAL in Australia to "wholesale clients" only. This material does not take into account the specific investment objectives, financial situation or particular needs of the recipient. The recipient of this material must not distribute it to any third party or outside Australia without the prior written consent of JPMSAL. For the purposes of this paragraph the term "wholesale client" has the meaning given in section 761G of the Corporations Act 2001. J.P. Morgan's research coverage universe spans listed securities across the ASX All Ordinaries index, securities listed on offshore markets, unlisted issuers and investment products which Research management deem to be relevant to the investor base from time to time. J.P. Morgan seeks to cover companies of relevance to the domestic and international investor base across all GIC sectors, as well as across a range of market capitalisation sizes. **Germany:** This material is distributed in Germany by J.P. Morgan Securities plc, Frankfurt Branch which is regulated by the Bundesanstalt für Finanzdienstleistungsaufsicht. **Korea:** This report may have been edited or contributed to from time to time by affiliates of J.P. Morgan Securities (Far East) Limited, Seoul Branch. **Singapore:** As at the date of this report, JPMSS is a designated market maker for certain structured warrants listed on the Singapore Exchange where the underlying securities may be the securities discussed in this report. Arising from its role as designated market maker for such structured warrants, JPMSS may conduct hedging activities in respect of such underlying securities and hold or have an interest in such underlying securities as a result. The updated list of structured warrants for which JPMSS acts as designated market maker may be found on the website of the Singapore Exchange Limited: http://www.sgx.com. In addition, JPMSS and/or its affiliates may also have an interest or holding in any of the securities discussed in this report – please see the Important Disclosures section above. For securities where the holding is 1% or greater, the holding may be found in the Important Disclosures section above. For all other securities mentioned in this report, JPMSS and/or its affiliates may have a holding of less than 1% in such securities and may trade them in ways different from those discussed in this report. Employees of JPMSS and/or its affiliates not involved in the preparation of this report may have investments in the securities (or derivatives of such securities) mentioned in this report and may trade them in ways different from those discussed in this report. **Taiwan**: Research relating to equity securities is issued and distributed in Taiwan by J.P. Morgan Securities (Taiwan) Limited, subject to the license scope and the applicable laws and the regulations in Taiwan. According to Paragraph 2, Article 7-1 of Operational Regulations Governing Securities Firms Recommending Trades in Securities to Customers (as amended or supplemented)

This document is being provided for the exclusive use of CHRISTOPHER Lee at JPMorgan Chase & Co. and clients of J.P. Morgan.

and/or other applicable laws or regulations, please note that the recipient of this material is not permitted to engage in any activities in connection with the material which may give rise to conflicts of interests, unless otherwise disclosed in the "Important Disclosures" in this material. **India:** For private circulation only, not for sale. **Pakistan:** For private circulation only, not for sale. **New Zealand:** This material is issued and distributed by JPMSAL in New Zealand only to "wholesale clients" (as defined in the Financial Advisers Act 2008). The recipient of this material must not distribute it to any third party or outside New Zealand without the prior written consent of JPMSAL. **Canada:** This report is distributed in Canada by or on behalf of J.P.Morgan Securities Canada Inc. The information contained herein is not, and under no circumstances is to be construed as an offer to sell securities described herein, or solicitation of an offer to buy securities described herein, in Canada or any province or territory thereof. The information contained herein is under no circumstances to be construed as investment advice in any province or territory of Canada and is not tailored to the needs of the recipient. **Dubai:** This report has been distributed to persons regarded as professional clients or market counterparties as defined under the DFSA rules. **Brazil:** Ombudsman J.P. Morgan: 0800-7700847 / ouvidoria.jp.morgan@jpmorgan.com.

General: Additional information is available upon request. Information has been obtained from sources believed to be reliable but JPMorgan Chase & Co. or its affiliates and/or subsidiaries (collectively J.P. Morgan) do not warrant its completeness or accuracy except with respect to any disclosures relative to JPMS and/or its affiliates and the analyst's involvement with the issuer that is the subject of the research. All pricing is indicative as of the close of market for the securities discussed, unless otherwise stated. Opinions and estimates constitute our judgment as of the date of this material and are subject to change without notice. Past performance is not indicative of future results. This material is not intended as an offer or solicitation for the purchase or sale of any financial instrument. The opinions and recommendations herein do not take into account individual client circumstances, objectives, or needs and are not intended as recommendations of particular securities, financial instruments or strategies to particular clients. The recipient of this report must make its own independent decisions regarding any securities or financial instruments mentioned herein. JPMS distributes in the U.S. research published by non-U.S. affiliates and accepts responsibility for its contents. Periodic updates may be provided on companies/industries based on company specific developments or announcements, market conditions or any other publicly available information. Clients should contact analysts and execute transactions through a J.P. Morgan subsidiary or affiliate in their home jurisdiction unless governing law permits otherwise.

"Other Disclosures" last revised April 04, 2020.

Copyright 2020 JPMorgan Chase & Co. All rights reserved. This report or any portion hereof may not be reprinted, sold or redistributed without the written consent of J.P. Morgan.

Completed 05 Jun 2020 10:16 AM EDT Disseminated 05 Jun 2020 11:13 AM EDT
This document is being provided for the exclusive use of CHRISTOPHER Lee at JPMorgan Chase & Co. and clients of J.P. Morgan.