Big Data in a Pandemic

Internet of living things – big data can save lives and economies

Global Quantitative and Derivatives Strategy

Marko Kolanovic, PhD AC
(1-212) 622-3677
marko.kolanovic@jpmorgan.com

Bram Kaplan, CFA
(1-212) 272-1215
bram.kaplan@jpmorgan.com

J.P. Morgan Securities LLC

Over the past few years we have been researching the use of big data in investing (see our primer on big data and machine learning here). Companies often utilize big data to monitor consumer spending patterns or assess corporate or economic activity in real time. With the outbreak of the COVID-19 pandemic, investors used big data to track air pollution, traffic congestion and shipping activity in China. In retrospect, big data should have been urgently mobilized in the more important tasks of saving lives and protecting economies. In this note we will propose a potential big data solution – 'internet of living things' – that can be employed to fight a pandemic and help in re-opening economies in its aftermath.

A leading authority in epidemics recently stated: "If you think you are in line with the outbreak, you are already three weeks behind." In the age of big data, machine learning and internet of things, this could be different, as technologies exist to have a real-time picture of a pandemic. Real-time assessment would allow authorities to be ahead of the virus, to optimize the response and resources, and to assess the effectiveness of measures taken. Why are traditional data always lagging the virus? When the first symptoms of an illness appears, most people wait some time to confirm the symptoms or wait in hope that initially mild symptoms go away. After several days they may seek medical help, but appointments or tests may not be immediately available. When virus tests are obtained, results may take several additional days to arrive. In all, from the first onset of symptoms to a confirmation of a disease, it may take 1 or 2 weeks, often even longer. If there is a pandemic outbreak, 1 or 2 weeks may mean that the virus is already spread out of control, before it even shows in official statistics.

Big data revolution came largely as a result of widespread use of internet-enabled smart phones and ability to process large quantities of structured and unstructured data in real time. There is no reason why anonymized, aggregate information about onset of disease symptoms could not be available and tracked by artificial intelligence in real time. Output of such a system would be used to prevent and contain pandemics, as well as manage re-opening of economies in the aftermath. In an analogy to the internet of things, we can call this system the 'internet of living things.' Below we roughly outline possible components of an 'internet of living things' – big data/AI system to prevent and mitigate global pandemics.

Of course, great care will need to be taken to ensure data is protected, anonymized and used only in aggregate, to prevent personal data from being stolen or manipulated by a malicious actor.

Marko Kolanovic, PhD
(1-212) 622-3677
marko.kolanovic@jpmorgan.com

Global pandemic 'daily roll call': similar to how many employers conduct daily roll calls of employees and track their health status, one could have a daily smartphone-based survey of the broad population. For instance, the survey could be administered via required landing page on iOS/Android smart phone devices, or via text messages (similar to emergency alerts). Each user would need to input their status regarding disease symptoms (e.g., temperature reading and other symptoms for individual and/or household members). A minute of time would be a small ask during a pandemic, but would provide likely the most comprehensive real-time picture of illness and its dynamics. Individual countries could also require the smart phone roll call by mandating it (similar to census), or tying it to specific government incentives (e.g., mobile payments to survey participants, consumption vouchers, health care credits, etc.).

Broad distribution of free diagnostic smart-devices: by providing free devices such as smart thermometers or other internet connected diagnostic tools (e.g., smart watch sensors, etc.), countries could create their own 'internet of living things' networks. From these networks, health authorities could obtain a real-time picture and be able to prevent and manage seasonal outbreaks, region-specific illnesses, or global pandemics. The internet of living things could be an ongoing system with its own economics, or it could be an emergency response system activated as a response to an epidemic.

Establishing of big data pandemic war rooms: either on a global, regional, or country level, these centers would be needed to process and analyze large volumes of complex data obtained from the 'internet of living things.' Once the data are processed, these war rooms of data scientists and health professionals would coordinate the response with appropriate authorities. Insights obtained from surveys or smart devices would allow governments to act during initial stages of an outbreak, manage containment measures, and later optimize reopening the economy (region by region, and in different phases), while managing and monitoring risks of creating secondary outbreaks in real time.

Make available all pandemic-relevant data to allow for crowdsourcing solutions: Many big data and AI challenges over the past years were solved with a method of crowdsourcing. A dataset is posted on a website, open for anyone to tackle it and find a solution (usually there is an award for a person who first solves the problem). Millions of talented scholars and data scientists across the developed and developing world would be available to seek and find a solution. Following this template, all the data relevant for the pandemic and remedies should be available on a central website in real time. Problems such as forecasting outbreaks, assessing prevention measures, assessing success rate of various treatments, etc., would likely be solved quicker and better via crowdsourcing. For example – recently there has been a lot of discussions on the effectiveness of malaria drug Hydroxycholorquine in the treatment of COVID-19. There are several inconclusive and incompatible studies about the efficacy of this drug (e.g., there are 2 papers from French authors, 2 from Chinese, 1 from Korean, various other data points from governments, hospitals and even individuals, and a number of ongoing official trials). If these data were available in real time, there would likely be a machine learning/AI-driven model that could combine the different datasets to produce a probability model for success of this drug (e.g., integration of traditional and unstructured data, partial and ongoing trial results, etc.). Such a machine learning /AI algorithm would allow medical professionals to make potentially life-saving decisions (be it to use or not to use) ahead of slower traditional statistical studies that are employed during 'peace time.' Finally, one could make available data such as 3D scans of all parts for various equipment such as masks, ventilators, etc., to allow for a distributed 3D printing supply chain.

Individualized AI assessment to re-enter economy: All of the 'internet of living things' data (e.g., specific to individual's health risk, immunity status, region specific risks to contract or spread disease in a particular region, etc.) could be processed by AI to recommend to an individual potential restrictions (or removal of restrictions) of travelling to certain areas, re-entering the workforce, etc. The recommendations would be produced based on an individual's as well as comprehensive 'internet of living things' real time data, and could reduce risk for the individual, for others, and could optimize re-starting of economy case by case, in different geographic regions and stages of pandemic.

We believe the creation of an 'internet of living things' to address pandemic risk should be an immediate and an ongoing priority.

In our last note, we featured one real-time big/alternative dataset that reports the occurrence of influenza like illness coming from kinsa thermometers (see here and further below in this note). As we mentioned before, we believe this dataset is very useful in tracking real-time outbreaks of atypical influenza-like illnesses across the country. We believe this dataset correctly pointed to COVID-19 outbreaks ahead of these outbreaks being reported in the media or being documented in official data releases. We also believe that this dataset provides useful insights on the efficacy of measures put in place to restrict the spread of all iLIs, which include COVID-19. As with any big/alternative dataset, answers are not readily available and there are various biases and limitations on what can and cannot be extracted from such a dataset.

To illustrate further our thinking process and explore the limitations of models, we have analyzed NYC iLI data in conjunction with various COVID-19 datasets made available by state authorities and hospitals. In this study, we are not trying to forecast an absolute number of cases, but rather provide an example of incorporating big/alternative data into model projections, illustrate modelling challenges (e.g., model design and how various assumptions impact the output), and gain insights on the timing of a potential hospitalization case inflection point.

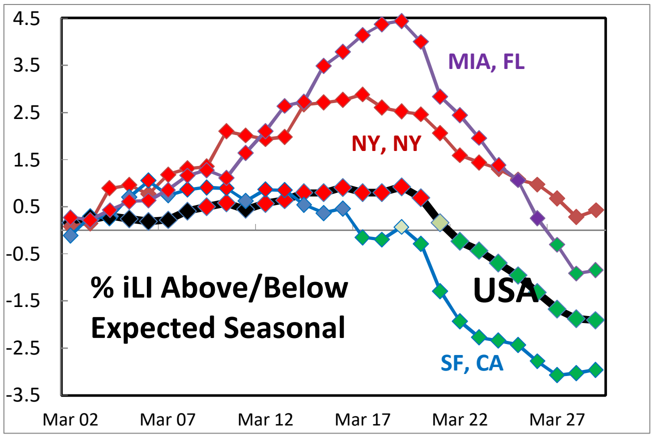
Our first assumption is that that the atypical increase of iLI in March is largely driven by COVID-19 cases, and that the decline of iLI is largely driven by implemented restrictions. However, one cannot infer how much of the iLI decline is due to a decline in cold/flu and how much is due to a decline in COVID-19. At one extreme (optimistic), all of the decline is due to a COVID-19 decline, and at the other extreme (pessimistic) none of decline is due to COVID-19 (note, however, cold/flu decline is also important as it frees up hospital capacity). The truth is likely somewhere in between, so we averaged the two scenarios. The second important assumption is on the recovery rate and timeline for COVID-19 cases. Here we took the available information on the average recovery time of ~2 weeks (for milder cases), and ~4 weeks recovery for severe cases, and fitted a smooth recovery curve for each day of atypical iLI. This approach can give us the model number of the total COVID-19 positive cases each day. This number is of course much larger than the number of test-confirmed cases (e.g., many COVID-19 cases won't be tested due to mild symptoms or being asymptomatic, self-isolation/home care, early recovery, unwillingness or inability to obtain a test, etc.). We believe that the number of tests confirmed is not the most relevant metric (e.g., in the 2017/2018 flu season there were ~45M flu cases, the vast majority of which weren't confirmed by testing), but rather the important metric is hospital admissions/loads that create risk of a health care system breakdown.

Inflection in hospital admissions is a function of actual number of cases, as well as the timeline of progression of cases from mild to severe, and hospitalization rates (currently averaging ~20% of confirmed cases). Hospitalization rates however lag the number of actual cases. As we argued initially, after the first onset of symptoms, there could be 1-2 weeks before a person is potentially hospitalized. In that time period, a significant fraction of mild cases will actually get better, eliminating the need for hospitalization. Hospitalization rates are themselves self-reflexive: the longer a person does not recover from COVID-19, the higher the likelihood of hospitalization. So we modeled hospitalization rates iteratively in conjunction with recovery rates. In other words, as the number of true cases declines (due to recovery of mild cases), % hospitalization of cases increases as they did not recover and are becoming severe/critical. Modeling recovery and hospitalization curves introduce additional uncertainty in our model. Our model indicates that the number of NYC infections peaked already (model indicates approximately 8 days ago) at a much larger number than current confirmed cases of 33,474. Due to the lag in recovery and hospitalization rate curves, our model shows peak hospitalization occurring this past weekend, with some ~17,000 cases. We don't rely on the total number of hospitalizations in our model as accurate, as it needs to be scaled with the total number of cases (which will likely never be fully known due to mild and asymptomatic cases). In fact we know our model is over-estimating the number of hospitalizations as the current actual number is only 7,410. We do have more confidence in the potential inflection in hospitalizations that our model indicates is happening now. Data from Sunday's press conference held by Gov. Cuomo show a meaningful slowdown in hospitalizations over the past 3 days, as well as a faster increase in hospital discharges than hospital admissions, both of which are roughly consistent with our model.

Figure 1 shows the % iLI above/below expected seasonal – an update of the chart from our last report (here). One can see a continued decline in atypical iLI nationally. In SF county, restrictive measures appear to be very successful and suppressed virtually all iLIs. In NY, iLI declined but is still significantly higher than the national level – as expected given how severe the NY outbreak is.

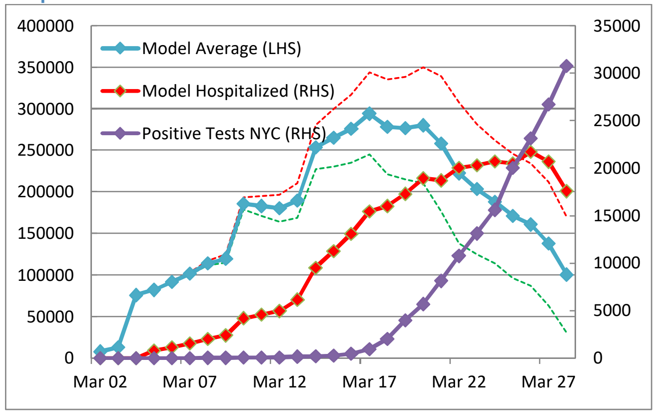
Figure 2 shows a model of NYC COVID-19 cases and hospitalization rates based on atypical iLI data, model recovery and hospitalization rates. Modeling steps/assumptions introduce uncertainty for absolute number estimates. However, the main features indicate that the number of active cases likely peaked already (model indicates ~8 days ago), and that hospitalization rates are possibly peaking now.

Figure 1: Incidence of atypical influenza-like illness by location over time



Source: kinsa, J.P. Morgan QDS.

Figure 2: Illustrative model of NYC COVID-19 cases and hospitalizations



Source: J.P. Morgan QDS.

Marko Kolanovic, PhD
(1-212) 622-3677
marko.kolanovic@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

This report is a product of the research department's Global Quantitative and Derivatives Strategy group. Views expressed may differ from the views of the research analysts covering stocks or sectors mentioned in this report. Structured securities, options, futures and other derivatives are complex instruments, may involve a high degree of risk, and may be appropriate investments only for sophisticated investors who are capable of understanding and assuming the risks involved. Because of the importance of tax considerations to many option transactions, investors considering options should consult with their tax advisor as to how taxes affect the outcome of contemplated option transactions.

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.

Explanation of Equity Research Ratings, Designations and Analyst(s) Coverage Universe:
J.P. Morgan uses the following rating system: Overweight [Over the next six to twelve months, we expect this stock will outperform the average total return of the stocks in the analyst's (or the analyst's team's) coverage universe.] Neutral [Over the next six to twelve months, we expect this stock will perform in line with the average total return of the stocks in the analyst's (or the analyst's team's) coverage universe.] Underweight [Over the next six to twelve months, we expect this stock will underperform the average total return of the stocks in the analyst's (or the analyst's team's) coverage universe.] Not Rated (NR): J.P. Morgan has removed the rating and, if applicable, the price target, for this stock because of either a lack of a sufficient fundamental basis or for legal, regulatory or policy reasons. The previous rating and, if applicable, the price target, no longer should be relied upon. An NR designation is not a recommendation or a rating. In our Asia (ex-Australia and ex-India) and U.K. small- and mid-cap equity research, each stock's expected total return is compared to the expected total return of a benchmark country market index, not to those analysts' coverage universe. If it does not appear in the Important Disclosures section of this report, the certifying analyst's coverage universe can be found on J.P. Morgan's research website, www.jpmorganmarkets.com.

J.P. Morgan Equity Research Ratings Distribution, as of January 02, 2020

	Overweight (buy)	Neutral (hold)	Underweight (sell)
J.P. Morgan Global Equity Research Coverage	45%	41%	15%
IB clients*	51%	47%	39%
JPMS Equity Research Coverage	43%	42%	14%
IB clients*	75%	64%	56%

*Percentage of subject companies within each of the "buy," "hold" and "sell" categories for which J.P. Morgan has provided investment banking services within the previous 12 months. Please note that the percentages might not add to 100% because of rounding.
For purposes only of FINRA ratings distribution rules, our Overweight rating falls into a buy rating category; our Neutral rating falls into a hold rating category; and our Underweight rating falls into a sell rating category. Please note that stocks with an NR designation are not included in the table above. This information is current as of the end of the most recent calendar quarter.

Equity Valuation and Risks: For valuation methodology and risks associated with covered companies or price targets for covered companies, please see the most recent company-specific research report at http://www.jpmorganmarkets.com, contact the primary analyst or your J.P. Morgan representative, or email research.disclosure.inquiries@jpmorgan.com. For material information about the proprietary models used, please see the Summary of Financials in company-specific research reports and the Company Tearsheets, which are available to download on the company pages of our client website, http://www.jpmorganmarkets.com. This report also sets out within it the material underlying assumptions used.

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.

All research reports made available to clients are simultaneously available on our client website, J.P. Morgan Markets. Not all research content is redistributed, e-mailed or made available to third-party aggregators. For all research reports available on a particular stock, please contact your sales representative.

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.

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 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) 058/04/2019 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) 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.

Marko Kolanovic, PhD
(1-212) 622-3677
marko.kolanovic@jpmorgan.com

"Other Disclosures" last revised March 08, 2020.