JPMorgan Chase Bank NA
Jesse Edgerton (1-212) 834-9543
jesse.edgerton@jpmchase.com
J.P. Morgan Securities LLC
Dan Weitzenfeld (1-646) 343-4033
dan.weitzenfeld@jpmorgan.com

Economic Research Note

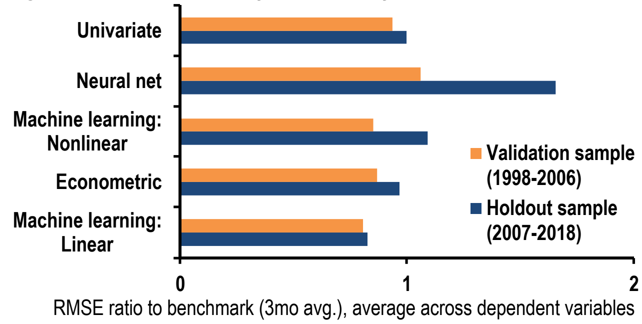
Machine learning for macro: What you really need to know

- **We cut through the hype and identify machine learning tools that macro forecasters should have in their toolbox**
- **Linear dimension reduction methods like principal components analysis and regularization methods like ridge regression work the best in small monthly or quarterly datasets**
- **Other ML and AI tools like random forests, boosted trees, support vector machines, and neural nets do no better and sometimes worse**
- **We publish nowcasters, recession risk trackers, and other tools based on the best techniques every day in the Real-time Quant Econ Monitor**

In a special report last week (Machine learning for macro: What you need to know), we detailed our research on the machine learning and artificial intelligence techniques that will be most useful to macroeconomic forecasters, and we summarize our results in this short note. In the last several years, artificial intelligence has made headlines by learning to drive cars, answer phone calls, and beat humans in chess, go, and Jeopardy. Yet macroeconomists have typically approached forecasting with simpler econometric tools built upon the workhorse Ordinary Least Squares (OLS) linear regression. To evaluate whether the new machine learning (ML) and artificial intelligence (AI) methods can improve our forecasting toolkit, we conduct an extensive horserace across a broad set of econometric and machine learning methods to predict a variety of macroeconomic data.

As in our prior work in 2016, we found that relatively simple, linear tools like OLS, principal components analysis (PCA), ridge regression, and the lasso perform best in in our context of short macroeconomic time series (Figure 1). The most flexible nonlinear ML and AI tools like random forests, boosted trees, support vector machines, and neural nets do no better, and sometimes much worse. Although these tools may be quite successful in learning how to recommend movies based on millions of ratings or detect credit card fraud from billions of transactions, they seem to add little value in our tiny datasets of a few hundred monthly observations. Their performance around the financial crisis was particularly bad in some cases, as these tools struggled to extrapolate outside the range of their prior experience.

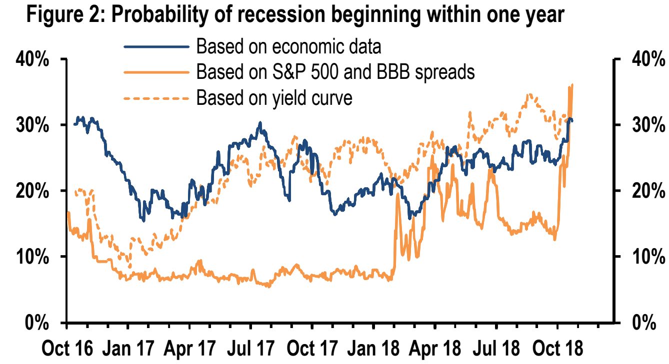
Figure 1: Forecast errors by model family



Source: J.P. Morgan

In short, we doubt that forecasters working with monthly or quarterly data have much to gain by adopting the most flexible AI methods. But the most successful linear ML methods may also be unfamiliar to many of our readers. So we demonstrate how these tools work in more detail, and we show how to use them to build forecasting models that use all available data, update in real time, and predict probabilities as well as mean forecasts. These methods power our nowcasters, recession risk trackers, and other models that we publish daily in the US Real-time Quant Econ Monitor (Figure 2).

Figure 2: Probability of recession beginning within one year



Source: Various government and non-government sources, J.P. Morgan

A horserace

The full report details the list of forecasting methods that we test, the macroeconomic variables that we forecast, and the grid search walk-forward cross-validation method that we use to optimize hyperparameters and evaluate model performance. Cutting to the chase, Table 1 lists the single model that performed best in predicting each of our six dependent variables during one-step-ahead validation periods through 2006, after choosing the best hyperparameters for each model type. For five out of our six dependent variables, the best-performing models were some combination of principal components analysis and a linear model like the ridge regression, elastic net, or the dynamic factor model. The pattern of linear model outperformance continues in our holdout period from 2007 to 2018.

JPMorgan Chase Bank NA
Jesse Edgerton (1-212) 834-9543
jesse.edgerton@jpmchase.com
J.P. Morgan Securities LLC
Dan Weitzenfeld (1-646) 343-4033
dan.weitzenfeld@jpmorgan.com

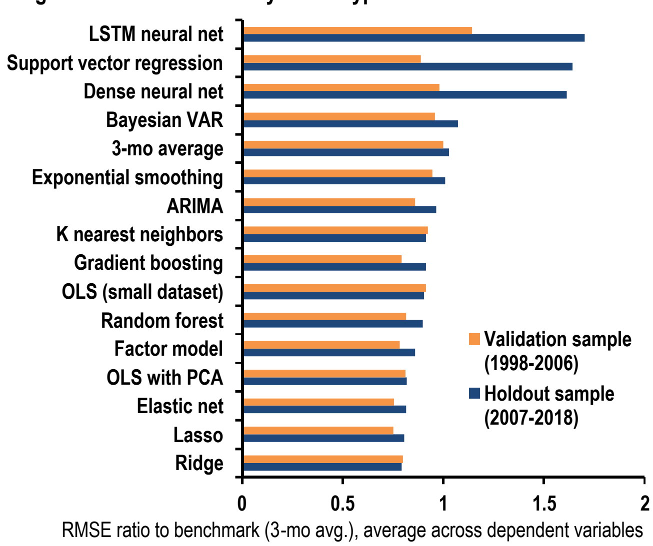
Table 1: Best performing models in validation and holdout samples

Target Variable		Validation sample	Holdout sample
Non-farm Payrolls	1-mo delta	Ridge with PCA	Elastic Net with PCA
	6-mo delta	Elastic Net	OLS with PCA
Retail Sales	1-mo delta	Factor Model	Random Forest
	6-mo delta	Factor Model	Factor Model
Core Capital Goods	1-mo delta	Random Forest	Elastic Net
	6-mo delta	Factor Model	OLS with PCA

Source: J.P. Morgan

Figure 1 places the RMSEs for all models across the six dependent variables on the same scale by dividing each model's RMSE by the RMSE of the 3-month average for that dependent variable in the holdout sample period. For each model family, we take the average RMSE across the individual models, where each model is represented by its single best hyperparameter combination. On average, the models in the linear family have the lowest error in both the training and holdout period. Figure 3 breaks out Figure 1 by showing the ratio of the RMSEs to the benchmark for each individual model, again averaged across our six dependent variables. The top five models in the holdout sample are all linear. To be fair, the best of the nonlinear machine learning models are not far behind, with the random forest and gradient boosting machine in sixth and eighth place. The differences between the RMSEs of these models are often minor in practical terms, but there is no sign of the nonlinear models doing better than the linear ones.

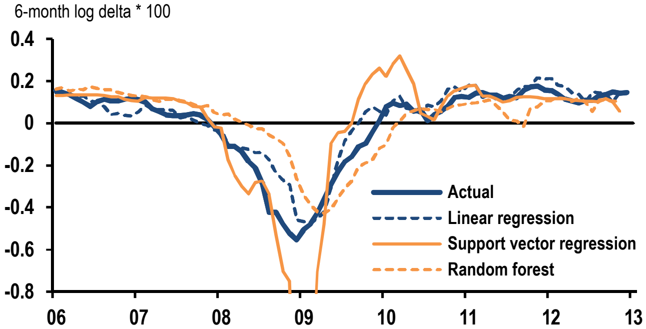
Figure 3: Forecast errors by model type



Source: J.P. Morgan

Some of the other, most flexible nonlinear models do badly in the holdout period, however, with the support vector regression and both kinds of neural nets producing holdout errors that are twice as large as the best performing linear models. Figure 4 further illustrates this poor performance by showing the 1-step-ahead forecasts for 6-month growth in nonfarm payrolls, using the best hyperparameters chosen from the validation sample for the linear regression on principal components, the support vector machine, and the random forest. The linear regression does not too badly compared to the actual data—by no means does it foresee the crisis, but once the recession began in early 2008, the linear model began to predict further job losses. The random forest also eventually began to predict job losses, but it was slower to come around to this realization. The support vector regression, on the other hand, began making predictions in late 2008 that turned out to be wildly too pessimistic, before swinging around and making overly optimistic predictions early in the recovery.

Figure 4: Nonfarm payrolls: 1-step ahead forecasts of 6-month growth



Source: J.P. Morgan

We suspect that the linear models perform best because they were better able to make sensible extrapolations based on past experience, while the nonlinear models struggled with this task. Random forests and other tree-based methods, for example, are fundamentally ill-equipped to extrapolate: because their predictions are essentially an average over the outcome of the most similar observations in the training set, they responded only slowly as the crisis deepened in 2008. In contrast, both the linear regression and the support vector regression are able to extrapolate beyond the observations they have seen in the training data. But the SVR is essentially extrapolating nonlinear functions outside the range over which they were estimated, which in this case results in wildly overshooting both the trough in 2009 and the recovery in 2010.

Understanding the linear models

Although the most successful linear techniques are on the simpler end of the range of models we consider, we suspect many of our readers are still less familiar with these tools than with workhorse OLS regressions. We thus provide a brief example to demonstrate how they work.

Table 2 shows results from five different models that predict monthly growth in core capital goods orders based on ten different surveys of businesses: the Institute for Supply Management (ISM) surveys for the manufacturing and nonmanu-

JPMorgan Chase Bank NA
Jesse Edgerton (1-212) 834-9543
jesse.edgerton@jpmchase.com
J.P. Morgan Securities LLC
Dan Weitzenfeld (1-646) 343-4033
dan.weitzenfeld@jpmorgan.com

facturing sectors, plus eight different surveys from regional Federal Reserve Banks. Before diving into the results, think for a moment what we should expect a “good" forecasting model would look like here. All of the business surveys are individually positively correlated with capital goods orders, and all are likely to capture a somewhat different selection of firms, so each could capture some unique bit of information not included in the others. Thus, while some of the surveys might be more useful than others, a sensible model would likely place a positive coefficient on each of them.

Table 2: Coefficients in predicting capital goods orders

RHS variable	OLS	PCA	Ridge	LASSO	Elastic-Net
ISM Manufacturing	1.495	0.091	0.119	0.708	0.572
ISM Nonman.	-0.587	0.083	0.010	0	0
Philly Fed Mfg.	0.386	0.088	0.091	0.020	0.162
Empire State Mfg.	-0.398	0.080	0.064	0	0
Kansas City Mfg.	0.194	0.079	0.095	0.053	0.131
Richmond Mfg.	-0.300	0.087	0.058	0	0
Dallas Mfg.	-0.559	0.091	0.072	0	0
NY Fed Nonman.	-0.236	0.079	0.034	0	0
Richmond Nonman.	-0.283	0.075	-0.026	-0.076	-0.265
Dallas Nonman.	0.931	0.089	0.079	0	0.131
Constant	0.084	0.084	0.084	0.084	0.084

Source: Census Bureau, ISM, Federal Reserve, J.P. Morgan. Figures are coefficients in model predicting monthly growth in core capital goods orders using normalized versions of the listed series. The estimation sample is 2007-2018, and hyperparameters for the models are set to illustrative values.

The first column of Table 2, however, shows that if we include all ten surveys in a simple Ordinary Least Squares regression in the data since 2007, they produce erratic and implausible coefficients. This is the classic “multicollinearity” problem with OLS—including multiple highly correlated variables on the right-hand-side produces erratic results. Table 2 also shows how the four linear machine learning models each handle this problem a bit differently. For the principal components model in the table, we calculate the first component of the surveys and include the component in an OLS regression to predict capital goods orders. We then compute the implied coefficient on each survey in the regression by taking the loading that each survey receives in the component and multiplying this by the coefficient on the component in the regression. This procedure shows that each survey effectively receives a small, positive coefficient in the regression.

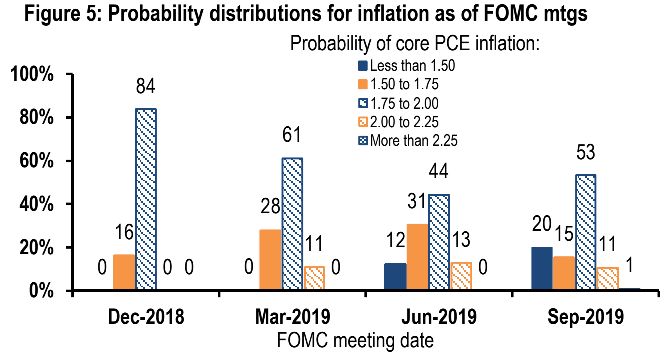
We also see that the ridge regression (which penalizes the sum of squared coefficients in the OLS regression) produces somewhat similar results, with most of the surveys receiving small positive coefficients but one a small negative. The lasso (which penalizes the absolute values of the coefficients instead of their squares) has the effect of setting some of the coefficients to zero, while still allowing a broad range of values across the nonzero coefficients. The elastic net looks like a combination of the ridge and lasso results in that it still sets some coefficients to zero, but spreads magnitudes more evenly across the nonzero coefficients.

One final consideration, however, is how useful the models will be in interpreting the data we receive each day as we fill in the jagged edge. Financial markets react to the implications of each data point we receive in real time, and they do not have the luxury of waiting until all data for the month are available before considering their implications. The lasso in Table 2 would thus be at a disadvantage. For example, it would entirely ignore the Empire State manufacturing survey and the New York Fed's services survey, which are among the very first of the business surveys we receive each month. When our clients ask us the meaning of a move in the Empire State index, the lasso would have no answer for them. Thus, in general, we tend to prefer models like the PCA and ridge regressions in the table, which we can use to help us interpret every data release in real time.

Conclusions and next steps

We conclude with practical recommendations for real-world forecasters. Although the most flexible nonlinear methods may not add much value for forecasters working with monthly or quarterly data, tools are available to build forecasting models that make use of all available data, update in real time, and predict probabilities as well as mean forecasts. In the full report, we demonstrate how to build models like this in both Eviews and Python, and we discuss the pros and cons of these and related packages. The models in our Quant Econ Monitor, which include predicted probabilities that update every day with new data (Figure 5), are based on these methods. We also discuss promising avenues for future research, including models that allow for regime changes and parameter shifts and using new and alternative data to monitor risks and vulnerabilities.

Figure 5: Probability distributions for inflation as of FOMC mtgs



Source: Various government and non-government sources, J.P. Morgan

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 ("JPM") is the global brand name for J.P. Morgan Securities LLC ("JPMS") and its affiliates worldwide. J.P. Morgan Cazenove is a marketing name for the U.K. investment banking businesses and EMEA cash equities and equity research businesses of JPMorgan Chase & Co. and its subsidiaries.

Principal Trading: J.P. Morgan and/or its affiliates normally make a market and trade as principal in fixed income securities discussed in this report.

Private Bank Clients: Where you are a client of the private banking businesses offered by JPMorgan Chase & Co. and its subsidiaries ("J.P. Morgan Private Bank"), research is issued 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 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. **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 (SEBI Registration Number - INB 230675231/INF 230675231/INE 230675231), the Bombay Stock Exchange Limited (SEBI Registration Number - INB 010675237/INF 010675237) 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) 099/04/2018 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) 046/09/2018], 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. **Saudi Arabia**: J.P. Morgan Saudi Arabia Ltd. is authorized by the Capital Market Authority of the Kingdom of Saudi Arabia (CMA) to carry out dealing as an agent, arranging, advising and custody, with respect to securities business under licence number 35-07079 and its registered address is at 8th Floor, Al-Faisaliyah Tower, King Fahad Road, P.O. Box 51907, Riyadh 11553, Kingdom of Saudi Arabia. **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.

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 coun-

tries, 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. **Hong Kong:** The 1% ownership disclosure as of the previous month end satisfies the requirements under Paragraph 16.5(a) of the Hong Kong Code of Conduct for Persons Licensed by or Registered with the Securities and Futures Commission. (For research published within the first ten days of the month, the disclosure may be based on the month end data from two months prior.) J.P. Morgan Broking (Hong Kong) Limited is the liquidity provider/market maker for derivative warrants, callable bull bear contracts and stock options listed on the Stock Exchange of Hong Kong Limited. An updated list can be found on HKEx website: http://www.hkex.com.hk. **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 persons whose principal business is the investment of money or who, in the course of and for the purposes of their business, habitually invest money. JPMSAL does not issue or distribute this material to members of "the public" as determined in accordance with section 3 of the Securities Act 1978. 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:** The information contained herein is not, and under no circumstances is to be construed as, a prospectus, an advertisement, a public offering, 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. Any offer or sale of the securities described herein in Canada will be made only under an exemption from the requirements to file a prospectus with the relevant Canadian securities regulators and only by a dealer properly registered under applicable securities laws or, alternatively, pursuant to an exemption from the dealer registration requirement in the relevant province or territory of Canada in which such offer or sale is made. 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. To the extent that the information contained herein references securities of an issuer incorporated, formed or created under the laws of Canada or a province or territory of Canada, any trades in such securities must be conducted through a dealer registered in Canada. No securities commission or similar regulatory authority in Canada has reviewed or in any way passed judgment upon these materials, the information contained herein or the merits of the securities described herein, and any representation to the contrary is an offence. **Dubai:** This report has been issued to persons regarded as professional clients 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 October 20, 2018.