JPMorgan Chase Bank NA
Jesse Edgerton (1-212) 834-9543
jesse.edgerton@jpmorgan.com

Economic Research Note

Quantifying risks to the US growth outlook

- **We test a variety of econometric and machine learning methods for predicting the distribution of GDP growth**
- **No methods are clear winners, and averaging predictions from several methods may be the best approach**
- **Based on these results, we put the probability that GDP grows faster than 3% in 2018 at about 30%**

Our baseline forecast continues to look for the US economy to grow above its trend in 2018, pulling the unemployment rate further down and pushing inflation up. But we know well that the chance of 2018 unfolding exactly as our forecast envisions is quite small, and thus we also spend considerable time weighing the likelihood of alternative outcomes. Notably, we have written extensively on our efforts to quantify the risk of a recession beginning within different time horizons. Despite the market volatility in recent days, our preferred model based on macroeconomic data still puts the probability of recession beginning within one year just above 20%.

In this note, we take a new approach and experiment with multiple methods for forecasting the distribution of GDP growth over the upcoming year—including potential upside scenarios. We conduct a "horserace" among several econometric and machine learning techniques to test which perform best in predicting the likelihood of different GDP outcomes in out-of-sample forecasting backtests. Focusing on the models' ability to predict the probability of growth above 3%, we find that various models' predictions are often similar, and no techniques are clear winners. An average of several techniques seems likely to provide the best estimates. Based on these results, we put the probability of 2018 GDP growth (4Q/4Q) being greater than 3% at about 30%. Results also suggest a risk of GDP growth below 1% at about 20%, although we still consider our recession model our preferred method of thinking about downside risks.

Opening up the playbook

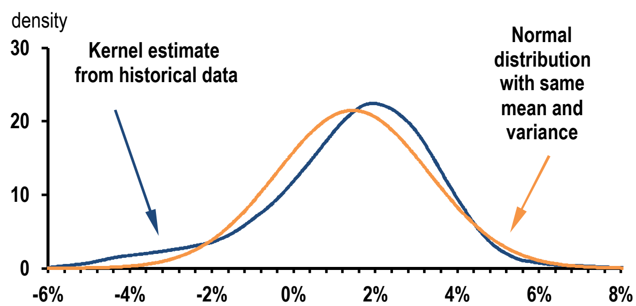
In this note we use historical data to inform our views on questions like the probability of GDP growing above or below certain rates. In this day and age, of course, there exists a vast menagerie of statistical, econometric, machine learning, or artificial intelligence techniques that one might use to perform this task. We do not attempt to evaluate all possible techniques (let alone all possible combinations of techniques), but instead choose a few different options that will provide some representation across a few different families of methods. We first briefly list and define the techniques we will consider before discussing their theoretical pros and cons and ultimately our empirical results.

1. OLS. The simplest method we use is an ordinary least squares (OLS) regression of a dummy variable for GDP growth above a given threshold on a set of predictor variables.

2. Probit. Also part of the standard econometrics toolbox, the probit model fits the same threshold dummy to a nonlinear function of the predictor variables.

3. Kernel density. We first fit an OLS regression of GDP growth itself (not the threshold dummy) on the predictor variables, then we fit a kernel density estimator to the residuals from this regression. The current estimate of this density is illustrated in Figure 1. The modal, or most likely, growth outcome is a bit above 2%, not far from our own forecast. But the estimated density illustrates that a wide range of other outcomes are possible. The estimated density also has a notably fatter tail of downside risk than a normal distribution with the same mean and variance.

Figure 1: Probability distribution for GDP growth in 2018



Source: J.P. Morgan

4. Quantile regression. We use quantile regressions to estimate, for example, the 90th percentile of GDP growth based on the predictor variables. We run many such quantile regressions and assign the relevant threshold probability to the quantile regression with the result nearest the threshold. For example, if the 72nd quantile regression predicted GDP growth at 3%, we would assign a 28% probability to growth at 3% or above.

5. Random forest classifier. Regression trees divide the space of predictor variables into regions based on combinations of the predictors. For example, all observations where lagged GDP growth is above some threshold while the output gap is below another threshold might be predicted to forecast the same probability of GDP growth above 3%. Random forests average together many different such trees, where there is some randomness in the estimation of the individual trees.

6. Boosted regression trees. Boosted trees are also based on the underlying idea of a regression tree, but additional layers of trees are estimated on the residuals of higher-level trees.

Thinking a bit about potential pros and cons, we note that all of the methods in our list will allow considerable flexibility for the estimates to fit the shape of the tails of the distribution of the data, and none impose a particular distributional form (like normality). We note that the kernel density approach in number 3 has the potential drawback of not allowing the predictor variables to have different effects on probabilities at different thresholds, but all other methods would allow a given predictor variable to have different effects on the probability of GDP growth above 3% and below 1%, for example. Methods 1 through 4 only allow the predictor variables to affect the probabilities through a particular functional form (which is predominantly linear) while methods 5 and 6 could allow the predictors and their interactions to affect the probabilities in quite flexible ways.

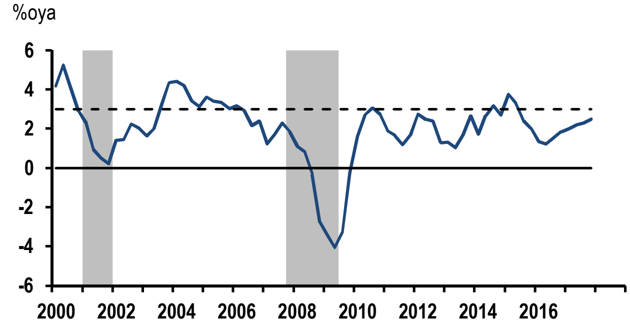
Taking some shots downfield

We use each of these methods to perform one-step-ahead, out-of-sample forecasts of the probability of GDP growth over the coming year being above a set of thresholds, in the data from 2000 to present. That is, we use data potentially observable as of 1999q4 to predict the distribution of average GDP growth from 2000q1 to 2000q4, then we use all the data through 2000q1 to predict the distribution of average GDP growth from 2000q2 to 2001q1, etc.

Our aim in this exercise is to test the effectiveness of the probability forecasting techniques while holding other aspects of the estimation constant, so we use the same set of predictor variables with each method and a 40-year rolling sample window. The predictor variables are working-age population growth over the prior two years (meant to capture shifts in potential growth in a way that could be observable in real time), the first principal component of a group of monthly indicators from our nowcaster growth model (meant to capture current growth momentum), and the level of the unemployment rate (which attempts to measure the stage of the business cycle in a manner similar to the "background risk" factor in our recession models). In regressions in data from recent decades, all variables enter the regression with the expected signs and are statistically significant at conventional levels.

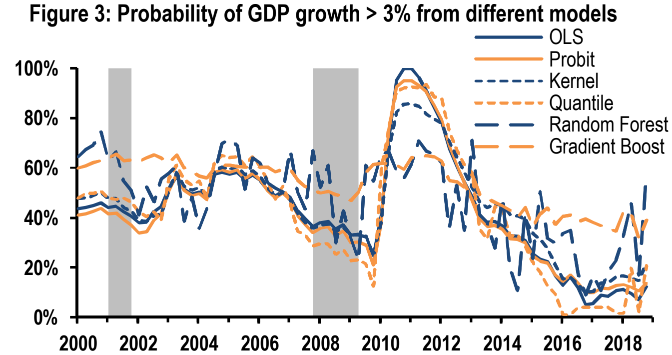
We illustrate the results by evaluating the models' success in predicting GDP growth greater than 3%, which has occurred 25% of the time in the data since 2000 (Figure 2). Figure 3 shows the one-step-ahead model-predicted probabilities of GDP growing above 3%. Overall the various methods we use for predicting the probabilities tend to produce similar results at a given time, which should not be surprising, as they are all based on the same data. We note that the models generally detect a decline in the probability of growth greater than 3% between the mid-2000s and today, a period over which the growth rate of the working-age population has declined by almost 1%-pt, contributing significantly to our long-held view that potential growth has slowed. Many of the models also saw a notable rise in the probability of 3% growth exiting the Great Recession, when the high unemployment rate suggested an economy with lots of open field ahead.

Figure 2: GDP growth and the 3% threshold



Source: BEA, J.P. Morgan

Figure 3: Probability of GDP growth > 3% from different models



Source: J.P. Morgan

Win some, lose some

But in general, the models appear to have had only limited success in picking out the 25% of years when GDP growth would run above 3%oya with much precision. Table 1 evaluates their performance more precisely by calculating their out-of-sample root-mean-squared-errors (RMSEs) in predicting whether GDP growth would run above 3% or below 1%. All the models do considerably better than a coin flip (which somewhat counterintuitively would have a RMSE of 0.71, the square root of 0.5), but they only narrowly outperform a rolling historical average. And differences across the models are slight—there is little indication that more complex, nonlinear models systematically outperform the simplest linear models. We do note that for both thresholds, the average across the several models does at least as well as any individual model, echoing a result commonly found in the forecasting literature.

At the moment, the average across these models would put the probability of 2018 4Q/4Q GDP growth running above 3% at 27%. We suspect the models may not fully capture the positive tone visible in many near-term data series right now and the likely effects of oncoming fiscal stimulus, so we round this figure up and conclude that the probability of GDP growth above 3% in 2018 is about 30%.

Table 1: RMSE in predicting GDP growth probabilities, 2000-2017

Model	> 3%	<1%
OLS	0.48	0.39
Probit	0.47	0.39
Kernel density	0.47	0.39
Quantile regression	0.47	0.41
Random forest	0.49	0.39
Boosted tree	0.52	0.41
Average of methods	0.47	0.39
Historical average	0.53	0.40
Coin flip	0.71	0.71

Source: J.P. Morgan

We could also use these models to take views on downside risks to our forecast; the model average would currently put the probability of GDP growth below 1% at about 20%. This is probably a mildly more optimistic view than our preferred recession model, which puts the probability of recession starting within one year at just above 20%. But in fact, we suspect that the recession model will still be our preferred tool for thinking about recession risks. In a sense, the recession model abstracts from the difficult problem of forecasting potential growth and focuses only on predicting large downside deviations from potential, while the growth-based models developed here must struggle to capture the factors that drive potential growth as well. In any case, we will continue to work on improving our understanding of these issues in future research.

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.

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. **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. **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 Australia Limited (JPMAL) (ABN 52 002 888 011/AFS Licence No: 238188) is regulated by ASIC and 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 Securities 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) 202/03/2017 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) 059/09/2017], 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 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. **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**: This material is issued and distributed in Taiwan by J.P. Morgan Securities (Taiwan) Limited. 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 January 01, 2018.