UBS | Global Research | 27 March 2017

# Quantessentials

## R advice – Bayesian regressions with stan

Equities

Global

Quantitative

David Jessop
Analyst
david.jessop@ubs.com
+44-20-7567 9882

Nick Baltas, PhD
Analyst
nick.baltas@ubs.com
+44-20-7568 3072

Claire Jones, CFA
Analyst
claire-c.jones@ubs.com
+44-20-7568 1873

Josie Gerken
Analyst
josephine.gerken@ubs.com
+44-20-7568 3560

Desi Ivanova
Associate Analyst
desi-r.ivanova@ubs.com
+44-20-7568 1754

Oliver Antrobus, CFA
Analyst
oliver.antrobus@ubs.com
+61-3-9242 6467

Josh Holcroft
Analyst
josh.holcroft@ubs.com
+852-2971 7705

Shanle Wu, PhD
Analyst
shanle.wu@ubs.com
+852-2971 7513

**The world of statistics is becoming more based on Bayesian techniques**

The increase in the speed of computing is allowing many more Bayesian approaches to be used in practical statistics. The advantage of Bayesian statistics are many both for model building and understanding the relationships between variables.

**A first step in a Bayesian direction**

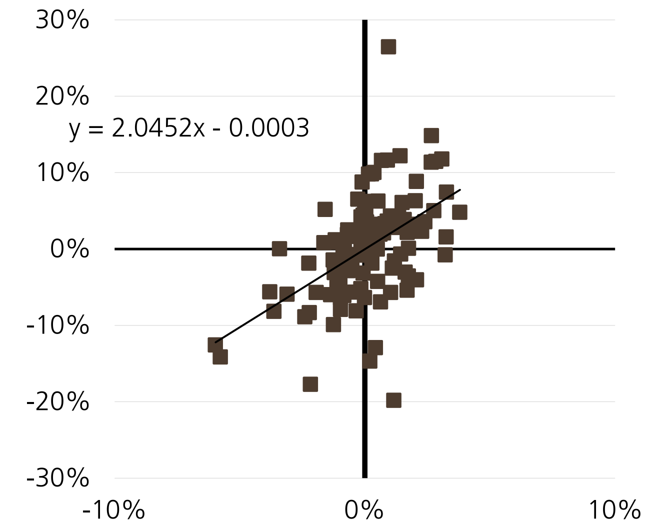
We have used Bayesian regressions to calculate the risk models in the UBS Portfolio Analysis System for some years, and find they have many advantages over using traditional regression. In this note we introduce how to carry out Bayesian regressions in R using the *rstan* and *rstanarm* packages.

## Do you want to be a Bayesian? [1]

In a companion note (Spotlight on…the blind reliance on Bloomberg betas, 27 March 2017) we discuss using relatively simple Bayesian techniques to estimate stock betas, in particular varying the amount of shrinkage depending on the fit of the basic regression of stock returns on market returns. Here we discuss how we estimated the Bayesian regressions using R.

Which of these two regression results below would you have the biggest confidence in? In Figure 1 we show the regression of Qorvo's returns on the S&P 500; in Figure 2 we show the regression of the Proshares Ultra S&P500 ETF (which is a 2x geared ETF) again on the S&P 500. In both cases we obtain an answer close to 2 but for the first the standard error is quite large (0.35) where as for the second it is tiny (0.008). So if we are considering "shrinking" the betas towards 1 then perhaps we should shrink Qorvo's beta by more than the ETF's. We can formalise this idea in a Bayesian regression.

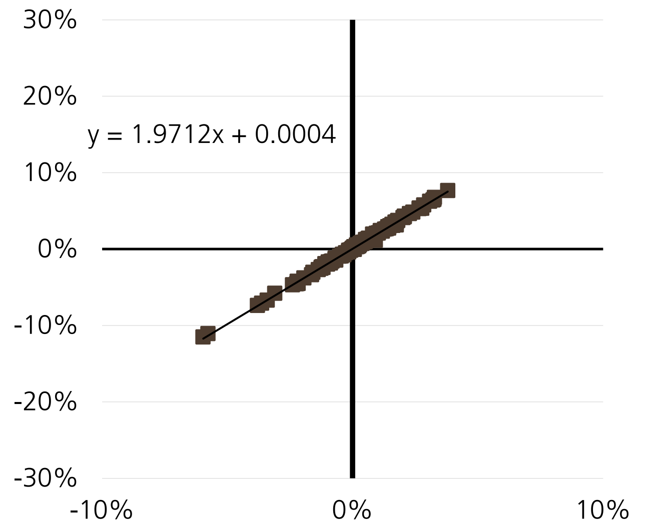
**Figure 1: Qorvo beta calculation**




```
           Estimate Std. Error
(Intercept)  0.000   0.006
SPX          2.045   0.349
```

Source: UBS. Stock used for example purposes only

**Figure 2: 2x ETF beta calculation**




```
           Estimate Std. Error
(Intercept) 0.000   0.000
SPX         1.971   0.008
```

Source: UBS

Kruschke (2015) says that "Bayesian data analysis has two foundational ideas. The first idea is that Bayesian inference is reallocation of credibility across possibilities. The second foundational idea is that the possibilities, over which we allocate credibility, are parameter values in meaningful mathematical models". What does this mean in our case? What do we know about betas? The first thing is that across all stocks in an index they are likely to have a mean of 1, and that most betas fall between around 0.4 and 1.6. So without any data we might decide that our initial allocation of credibility (or probability) could be expressed as saying betas are distributed as N (1, 0.3). This is called our prior distribution. We then introduce the data (in this case the stock and market returns) and these then change this distribution of credibility as shown in Figure 5 below. The purple line is our view of

[1] One feels there is a whole song with this title to the tune of "Do you want to build a snowman?" from Frozen.

the world with no information (our "prior" view); the black line is the distribution of the data and the blue line is our "reallocated" (or "posterior") credibility for the beta of Qorvo.

This is putting into words what Bayes rule does. We are not going to attempt to introduce the intricacies of Bayesian techniques in this note; just how we ran the regression. Kruschke (2015) and McElreath (2016) are good introductions to the topic, and Gelman et al (2013) is a good reference.

We note that our prior could be more sophisticated. We might know the industry in which the stock lies – if it's a technology stock we might expect the mean to be greater than one; if it's a utility then it would probably be less than one. This topic was discussed at our 2015 London Quantitative Conference by Mathijs Cosemans where he presented his paper "Estimating Security Betas Using Prior Information Based on Firm Fundamentals" (Cosemans et al, 2016). There is a summary of his paper available here.

The CRAN Task View for Bayesian Inference (at https://CRAN.R-project.org/view=Bayesian) is rather long to say the least. For our problem of estimating betas using a Bayesian regression we looked at two related packages:, rstan and rstanarm[2]. As always with R there are other approaches which can also be used.

The easiest approach is to use *rstanarm* which has functions which are designed to replace the standard R functions: in this case we could replace *lm* with *stan_lm* or *stan_glm*. *rstan* takes a little more work to get started but has the advantage of flexibility. We begin by running the usual linear regressions.

**Figure 3: Basic linear regressions**

```
twoStocks <- read.csv ("two stocks.csv") ## Contains the index too

summary (lm (SSO ~ SPX, data = twoStocks)) ## SSO is 2x geared ETF

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 0.0003540  0.0001392   2.544   0.0125 *
SPX         1.9712264  0.0079144 249.068   <2e-16 ***

## QRVO is the stock
summary (qrvoLM <- lm (QRVO ~ SPX, data = twoStocks))

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) -0.0002968  0.0061417  -0.048    0.962
SPX          2.0452491  0.3492801   5.856 5.95e-08 ***
```

Source: UBS

As already mentioned, the *rstanarm* package is designed to simply replace the lm call above. The *stan_lm* function uses an odd way of expressing the priors and so it turns out to be easier to use the *stan_glm* function.

Our model is

[2] We also wanted to use the *bugs* and *jags* based packages, *rjags* and *runjags* but these need the installation of the *WinBUGS* and *jags* programs which we could not access from within UBS.

$$r_{stock} \sim N(\beta_1 + \beta_2 r_{market}, \sigma)$$

Hence we need priors for the three parameters. For the slope (the parameter in which we are primarily interested) we are using an informative prior of a normal distribution with a mean of 1 and a standard deviation of 0.3. For the intercept and the standard deviation term we will use an uninformative prior - a very broad distribution - effectively saying we know little about their values. The prior for the standard deviation term is taken from Gelman (2006) – and is the default for *stan_glm* - which is a Cauchy distribution.

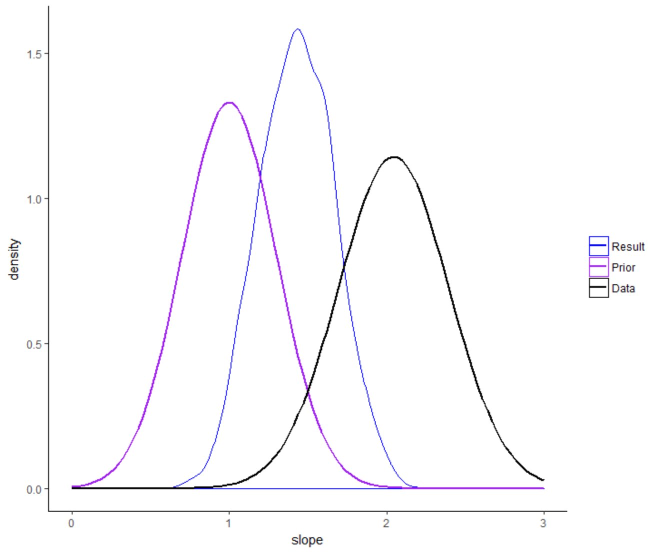
**Figure 4: Bayesian regressions with rstanarm**

```
library (rstan)
library (coda)
library (rstanarm)

ssoStan = stan_glm(SSO ~ SPX,  data = twoStocks,
         family = gaussian(),
         prior = normal(1, 0.3, autoscale = FALSE),
         prior_intercept = normal(0, 10, autoscale = FALSE),
         prior_aux = cauchy (0, 2.5), chains = 1,
         cores = 4, seed = 1)
summary (ssoStan)

Estimates:
                mean   sd    2.5%   25%   50%   75%   97.5%
(Intercept)     0.0    0.0   0.0    0.0   0.0   0.0   0.0
SPX             2.0    0.0   2.0    2.0   2.0   2.0   2.0
sigma           0.0    0.0   0.0    0.0   0.0   0.0   0.0
mean_PPD        0.0    0.0   0.0    0.0   0.0   0.0   0.0
log-posterior 511.6    1.2 508.3  511.2 512.0 512.5 512.9

qrvoStan <- stan_glm(QRVO ~ SPX,  data = twoStocks,
            family = gaussian(),
            prior = normal(1, 0.3, autoscale = FALSE),
            prior_intercept = normal(0, 10, autoscale = FALSE),
            prior_aux = cauchy (0, 2.5), chains = 1,
            cores = 4, seed = 1)
summary (qrvoStan)

Estimates:
                mean   sd    2.5%   25%   50%   75%   97.5%
(Intercept)     0.0    0.0   0.0    0.0   0.0   0.0   0.0
SPX             1.4    0.2   1.0    1.3   1.4   1.6   1.9
sigma           0.1    0.0   0.1    0.1   0.1   0.1   0.1
mean_PPD        0.0    0.0   0.0    0.0   0.0   0.0   0.0
log-posterior 127.9    1.2 124.9  127.3 128.2 128.8 129.3

# McElreath suggests not using 0.95 but another number to save
# confusion with traditional significance levels
posterior_interval (qrvoStan, prob = 0.89)

                    5.5%      94.5%
(Intercept) -0.009780303 0.01129120
SPX          1.068053097 1.79135148
sigma        0.056798832 0.07129282
```

Source: UBS

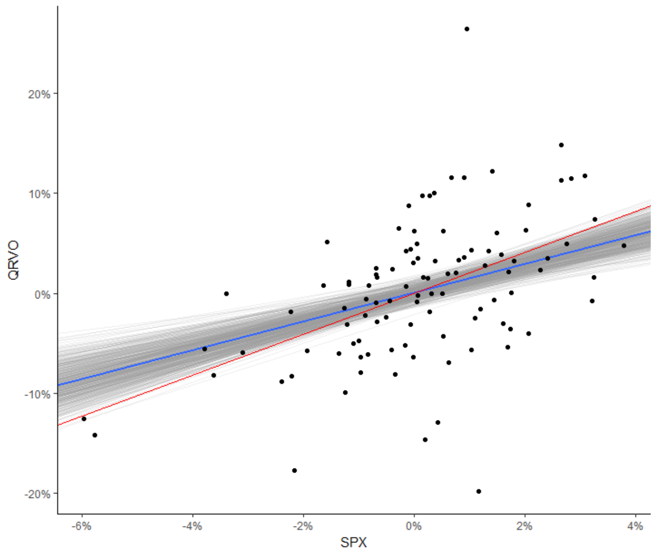
For the ETF the Bayesian regression leaves the estimated beta unchanged – the estimate of the slope from the regression is so "confident" it overrides any shrinkage. The estimate of the beta for QRVO however falls to around 1.4 and as we see from the bottom of Figure 4 it lies between 1.03 and 1.78.

**Figure 5: Distribution of betas for QRVO**




Source: UBS

**Figure 6: Bayesian regression for QRVO**




Source: UBS. The red line shows the result from a simple regression, the blue line is the median estimate from the Bayesian regression.

Using *rstan* directly involves writing a small model specification file. The advantage of this approach is you can very explicitly set out all your assumptions about the model; the downside is that you have to learn the syntax – not that tricky but another potential source of error. In Figure 7 we show the file we used in this case[3]. The first part of the *stan* file sets out the variables we are using – here the stock and the market returns. The second the parameters of the model; and the third the model itself. The priors are identical to those used above. We save the specification in a file called "simpleRegression.stan".

**Figure 7: Stan model file – simpleRegression.stan**

```
data {
  int<lower=0> N;
  vector[N] stock;
  vector[N] spx;
}
parameters {
  vector[2] beta;
  real<lower=0> sigma;
}
model {
  beta[1] ~ normal (0, 10);
  beta[2] ~ normal (1, 0.3);  // prior for slope
  sigma ~ cauchy (0, 2.5);
  stock ~ normal(beta[1] + beta[2] * spx, sigma);
}
```

Source: UBS

[3] Very much inspired by the example files available at https://github.com/stan-dev/example-models/wiki.

After we have created the specification we run the model as shown in Figure 8. The first time running any particular model is very slow as *rstan* builds some C++ code on the fly and then compiles it (this has already been done for *rstanarm*). This only needs to be done once.  You will note we create the variables with the same names as in the .stan file above.

**Figure 8: Running the regression using rstan**

```
stock <- twoStocks$SSO
spx <- twoStocks$SPX
N <- length (spx)

data.list.1 <- c ("N", "stock", "spx")
sso_res <- stan(file = "simpleRegression.stan",
                data = data.list.1, iter = 1000)
sso_res

Inference for Stan model: simpleRegression.
4 chains, each with iter=1000; warmup=500; thin=1;
post-warmup draws per chain=500, total post-warmup draws=2000.

          mean se_mean   sd   2.5%    25%    50%    75%  97.5% n_eff Rhat
beta[1]   0.00    0.00 0.00   0.00   0.00   0.00   0.00   0.00  2000 1.00
beta[2]   1.97    0.00 0.01   1.96   1.97   1.97   1.98   1.99   890 1.01
sigma     0.00    0.00 0.00   0.00   0.00   0.00   0.00   0.00   818 1.01
lp__    612.50    0.05 1.11 609.58 611.98 612.81 613.30 613.77   605 1.00

Samples were drawn using NUTS(diag_e) at Tue Mar 07 18:07:55 2017.
For each parameter, n_eff is a crude measure of effective sample size,
and Rhat is the potential scale reduction factor on split chains (at
convergence, Rhat=1).

stock <- twoStocks$QRVO

qrvo_res <- stan(file = "simpleRegression.stan", data = data.list.1, iter = 1000)
qrvo_res

          mean se_mean   sd   2.5%    25%    50%    75%  97.5% n_eff Rhat
beta[1]   0.00    0.00 0.01  -0.01   0.00   0.00   0.00   0.01  2000    1
beta[2]   1.43    0.01 0.23   0.97   1.26   1.43   1.59   1.88  2000    1
sigma     0.06    0.00 0.00   0.06   0.06   0.06   0.07   0.07  2000    1
lp__    228.75    0.04 1.21 225.54 228.19 229.07 229.65 230.15   933    1
```

Source:  UBS

We see that the answers are identical to those from *rstanarm*.  To generate Figure 6 we use the code below

**Figure 9: Producing the chart above**

```
beta.post.1 <- extract(qrvo_res, "beta")$beta
colnames (beta.post.1) = c ("intercept", "slope")
beta.mean.1 <- colMeans(beta.post.1)

alpha_level <- .15
col_draw <- "grey60"
col_median <-  "#3366FF"

# Plot a random sample of rows as gray semi-transparent lines
ggplot(twoStocks) +
  aes(x = SPX, y = QRVO) +
  geom_abline(aes(intercept = intercept, slope = slope),
              data = sample_n (as.data.frame (beta.post.1), 500),
              color = col_draw, alpha = alpha_level) +
  # Plot the median values in blue
  geom_abline(intercept = median(beta.post.1 [, 1]),
              slope = median(beta.post.1 [, 2]),
              size = 1, color = col_median) +
  # Results from the lm call
  geom_abline (intercept = coef (qrvoLM)[1],
      slope = coef (qrvoLM)[2], colour = "red") +
  geom_point() +
  scale_y_continuous(labels = scales::percent) +
  scale_x_continuous(labels = scales::percent) +
  theme_classic ()
```

Source: UBS

Suppose one wanted to run a Fama French regression, then one would have to specify priors on all the regression parameters. Figure 10 below shows part of the stan file that could do this (where in the Fama-French case K would be 3). This shows one can use loops within the stan file.

**Figure 10: stan file (part) for multiple linear regression**

```
data {
  int<lower=0> K; // number of predictors
}
parameters {
  vector[4] beta;
  real<lower=0> sigma;
}
model {
  beta[1] ~ normal (0,10); //prior for the intercept
  beta[2] ~ normal (1, 0.3); // prior for the market term
  for(i in 2:K)
    beta[i] ~ normal (0,1);//prior for the other slopes
}
```

Source: UBS

This has been a very basic introduction to running Bayesian regressions – we will return to the topic in a future Quantessentials looking at some of the diagnostics available and how to write more general models.

## Appendix

### R environment

We used R version 3.3.1 for our tests. The files were written to and from our local hard drive in order to lessen any delays caused by our network. It is running on an Intel i7-6700 running at 3.4GHz.

We show below the version numbers of the packages we used.

**Figure 11: Package versions used**

| Package | Version | Package | Version |
|---|---|---|---|
| rstan | 2.14.1 | rstanarm | 2.14.1 |
| coda | 0.18.1 | | |

Source: UBS

### References


Cosemans, M., R. Frehen, P. C. Schotman & R. Bauer (2016) Estimating Security Betas Using Prior Information Based on Firm Fundamentals, Review of Financial Studies 29(4) 1072-1112.

Gelman, A. (2006) Prior distributions for variance parameters in hierarchical models, Bayesian Analysis, 1(3) 515-533.

Gelman, A., J.B. Carlin, H.S. Stern, D.B. Dunson, A. Vehtari & D.B. Rubin (2013) Bayesian Data Analysis, Third Edition. Chapman & Hall/CRC Texts in Statistical Science.

Kruschke, John K. (2015) Doing Bayesian Data Analysis: A Tutorial with R, JAGS and Stan. Academic Press / Elsevier.

McElreath, Richard (2016) Statistical Rethinking: A Bayesian Course with Examples in R and Stan. Chapman & Hall / CRC Texts in Statistical Science.

## Research Publications

| Monographs, Keys and Q-Series | | Academic Research Monitor | |
|---|---|---|---|
| Title | Date | Topic | Date |
| What times the bond market? | Mar-17 | Where does Volatility Targeting Work? | Jan-17 |
| Passive opportunities for active managers | Feb-17 | ESG Quant Investing | Dec-16 |
| Active vs Passive: How will the World of Investing Evolve? | Jan-17 | Quality, Low-Risk and Momentum Investing | Nov-16 |
| What will demographics mean for growth and stock market returns? | Jan-17 | Combining Smart Beta Factors | Sep-16 |
| How to pick stocks in China's domestic market a quant perspective | Jan-17 | Portfolio Construction and Overfitting | Jul-16 |
| Systematic strategies for single-stock futures | Oct-16 | European Quantitative Conference 2015 Highlights | Apr-16 |
| Irrational asset management | Oct-16 | Does Oil matter for Equity Markets? | Mar-16 |
| China domestic market – alpha opportunities for quantitative investors | Oct-16 | Low Risk Investing | Feb-16 |
| When is the stock market likely to correct? | Oct-16 | Value Investing | Dec-15 |
| Are you already timing styles successfully? | Sep-16 | Analyst Forecasts and Measuring Distance | Nov-15 |
| Do low-volatility stocks have interest-rate risk? | Sep-16 | UBS Market Microstructure Conference | Oct-15 |
| What does splitting the financials sector change? | Aug-16 | Equity Risk Premium Forecasting and Market Timing | Sep-15 |
| Harvesting Yield from Cross-Asset Carry | Aug-16 | Behavioural Investing Patterns | Jul-15 |
| When is the stock market likely to correct? | Aug-16 | Quality and Size Investing | May-15 |
| Is it easier to be a quant in small cap? | Aug-16 | European Quantitative Conference 2015 Highlights | Apr-15 |
| Follow the smart money | Jul-16 | Smart Beta, Factors and Style Investing | Feb-15 |
| How can supply chains improve earnings visibility? | Jul-16 | Momentum-Investing | Jan-15 |
| Where are the attractive dividend paying stocks? | Mar-16 | Investment Strategies & Textual Analysis Signals | Dec-14 |
| Why does increasing volatility matter? | Feb-16 | Commodity Risk & Institutional Investing Habits | Nov-14 |
| What crowded positions are bubbling up in equity markets | Feb-16 | Index Membership, Investor (in)attention to News & Spurious Correlations | Sep-14 |
| What happened to Value, and when will it return? | Jan-16 | Forecasting the Equity Risk Premium | Aug-14 |
| Who benefits from automation? | Nov-15 | Implied Cost of Capital & Shorting Premium | Jun-14 |
| The Spectre of Equity-Bond allocation | Nov-15 | Trend Following | Mar-14 |
| Dynamic Asset Allocation | Nov-15 | Factor investing & Quality | Feb-14 |
| How will demographics shape investing for the next ten years? | Nov-15 | Quality & Gross Profitability | Jan-14 |
| Surfing the macro wave | Sep-15 | Minimum variance: valuation, concentration and exchange rates | Dec-13 |
| Low-Risk Investing: perhaps not everywhere | Jul-15 | Liquidity & back test overfitting | Oct-13 |
| The Madness of Crowds | Jul-15 | | |
| Understanding Size Investing | Jun-15 | | |

PAS User Guides

| | | | |
|---|---|---|---|
| PAS Macros | Feb-16 | Reports | Apr-14 |
| Quick Reference Guide | Nov-15 | Risk Parity | Feb-13 |
| Risk Parity and Composite Assets | Jan-15 | Advanced Analysis | Oct-12 |
| Introduction to the UBS Portfolio Analysis System | Jan-15 | Risk Models | Nov-11 |
| Long-Short Analysis | Jan-15 | UBS Hybrid Risk Model | Dec-10 |
| Installation | May-14 | Quick Portfolio Analysis | Jul-10 |

R Advice

| | | | |
|---|---|---|---|
| data.table: the best package in the world? | Mar-16 | Getting started with random forests | Sep-16 |
| R and Excel | Dec-16 | Optimising in R | Aug-16 |
| Rollin' Rollin' Rollin' | Oct-16 | Speeding up R / Plotting correlation matrices | Jun-16 |


## UK – London

| | |
|---|---|
| Nick Baltas | +44-20-7568 3072 |
| Maylan Cheung | +44-20-7568 4477 |
| Ian Francis | +44-20-7568 1872 |
| Josie Gerken | +44-20-7568 3560 |
| Simon Iley | +44-20-7568 6327 |
| Desi Ivanova | +44-20-7568-1754 |
| David Jessop | +44-20-7567 9882 |
| Claire Jones | +44-20-7568 1873 |
| Manoj Kothari | +44-20-7568 1997 |
| Simon Stoye | +44-20-7568 1876 |
| Christine Vargas | +44-20-7568 2409 |

## Hong Kong

| | |
|---|---|
| Cathy Fang (Shanghai) | +86-021-3866 8891 |
| Josh Holcroft | +852-2971 7705 |
| Shanle Wu | +852-2971 7513 |

## Australia– Sydney

| | |
|---|---|
| Oliver Antrobus | +61-3-9242 6467 |
| Luke Brown | +61-2-9324 3620 |
| Pieter Stoltz | +61-2-9324 3779 |
| Paul Winter | +61-2-9324 2080 |
| Jenevieve Zhang | +61-2-9324 2247 |

## Required Disclosures

This report has been prepared by UBS Limited, an affiliate of UBS AG. UBS AG, its subsidiaries, branches and affiliates are referred to herein as UBS.

For information on the ways in which UBS manages conflicts and maintains independence of its research product; historical performance information; and certain additional disclosures concerning UBS research recommendations, please visit www.ubs.com/disclosures. The figures contained in performance charts refer to the past; past performance is not a reliable indicator of future results. Additional information will be made available upon request. UBS Securities Co. Limited is licensed to conduct securities investment consultancy businesses by the China Securities Regulatory Commission. UBS acts or may act as principal in the debt securities (or in related derivatives) that may be the subject of this report. This recommendation was finalized on: 27 March 2017 03:20 AM GMT.

**Analyst Certification:** Each research analyst primarily responsible for the content of this research report, in whole or in part, certifies that with respect to each security or issuer that the analyst covered in this report: (1) all of the views expressed accurately reflect his or her personal views about those securities or issuers and were prepared in an independent manner, including with respect to UBS, and (2) no part of his or her compensation was, is, or will be, directly or indirectly, related to the specific recommendations or views expressed by that research analyst in the research report.

**UBS Investment Research: Global Equity Rating Definitions**

| 12-Month Rating | Definition | Coverage[1] | IB Services[2] |
|---|---|---|---|
| **Buy** | FSR is > 6% above the MRA. | 45% | 29% |
| **Neutral** | FSR is between -6% and 6% of the MRA. | 39% | 27% |
| **Sell** | FSR is > 6% below the MRA. | 15% | 16% |
| **Short-Term Rating** | **Definition** | **Coverage[3]** | **IB Services[4]** |
| **Buy** | Stock price expected to rise within three months from the time the rating was assigned because of a specific catalyst or event. | <1% | <1% |
| **Sell** | Stock price expected to fall within three months from the time the rating was assigned because of a specific catalyst or event. | <1% | <1% |

Source: UBS. Rating allocations are as of 31 December 2016.
1:Percentage of companies under coverage globally within the 12-month rating category.
2:Percentage of companies within the 12-month rating category for which investment banking (IB) services were provided within the past 12 months.
3:Percentage of companies under coverage globally within the Short-Term rating category.
4:Percentage of companies within the Short-Term rating category for which investment banking (IB) services were provided within the past 12 months.

**KEY DEFINITIONS: Forecast Stock Return (FSR)** is defined as expected percentage price appreciation plus gross dividend yield over the next 12 months. **Market Return Assumption (MRA)** is defined as the one-year local market interest rate plus 5% (a proxy for, and not a forecast of, the equity risk premium). **Under Review (UR)** Stocks may be flagged as UR by the analyst, indicating that the stock's price target and/or rating are subject to possible change in the near term, usually in response to an event that may affect the investment case or valuation. **Short-Term Ratings** reflect the expected near-term (up to three months) performance of the stock and do not reflect any change in the fundamental view or investment case. **Equity Price Targets** have an investment horizon of 12 months.

**EXCEPTIONS AND SPECIAL CASES: UK and European Investment Fund ratings and definitions are: Buy:** Positive on factors such as structure, management, performance record, discount; **Neutral:** Neutral on factors such as structure, management, performance record, discount; **Sell:** Negative on factors such as structure, management, performance record, discount. **Core Banding Exceptions (CBE):** Exceptions to the standard +/-6% bands may be granted by the Investment Review Committee (IRC). Factors considered by the IRC include the stock's volatility and the credit spread of the respective company's debt. As a result, stocks deemed to be very high or low risk may be subject to higher or lower bands as they relate to the rating. When such exceptions apply, they will be identified in the Company Disclosures table in the relevant research piece.

Research analysts contributing to this report who are employed by any non-US affiliate of UBS Securities LLC are not registered/qualified as research analysts with FINRA. Such analysts may not be associated persons of UBS Securities LLC and therefore are not subject to the FINRA restrictions on communications with a subject company, public appearances, and trading securities held by a research analyst account. The name of each affiliate and analyst employed by that affiliate contributing to this report, if any, follows.

**UBS Limited:** David Jessop; Nick Baltas, PhD; Claire Jones, CFA; Josie Gerken, PhD; Desi Ivanova. **UBS Securities Australia Ltd:** Oliver Antrobus, CFA. **UBS AG Hong Kong Branch:** Josh Holcroft; Shanle Wu, PhD.

Unless otherwise indicated, please refer to the Valuation and Risk sections within the body of this report. For a complete set of disclosure statements associated with the companies discussed in this report, including information on valuation and risk, please contact UBS Securities LLC, 1285 Avenue of Americas, New York, NY 10019, USA, Attention: Investment Research.

## Global Disclaimer

This document has been prepared by UBS Limited, an affiliate of UBS AG. UBS AG, its subsidiaries, branches and affiliates are referred to herein as UBS.

Global Research is provided to our clients through UBS Neo and, in certain instances, UBS.com (each a "System"). It may also be made available through third party vendors and distributed by UBS and/or third parties via e-mail or alternative electronic means. The level and types of services provided by Global Research to a client may vary depending upon various factors such as a client's individual preferences as to the frequency and manner of receiving communications, a client's risk profile and investment focus and perspective (e.g., market wide, sector specific, long-term, short-term, etc.), the size and scope of the overall client relationship with UBS and legal and regulatory constraints.

All Global Research is available on UBS Neo. Please contact your UBS sales representative if you wish to discuss your access to UBS Neo.

When you receive Global Research through a System, your access and/or use of such Global Research is subject to this Global Research Disclaimer and to the terms of use governing the applicable System.

When you receive Global Research via a third party vendor, e-mail or other electronic means, your use shall be subject to this Global Research Disclaimer and to UBS's Terms of Use/Disclaimer (http://www.ubs.com/global/en/legalinfo2/disclaimer.html). By accessing and/or using Global Research in this manner, you are indicating that you have read and agree to be bound by our Terms of Use/Disclaimer. In addition, you consent to UBS processing your personal data and using cookies in accordance with our Privacy Statement (http://www.ubs.com/global/en/legalinfo2/privacy.html) and cookie notice (http://www.ubs.com/global/en/homepage/cookies/cookie-management.html).

**If you receive Global Research, whether through a System or by any other means, you agree that you shall not copy, revise, amend, create a derivative work, transfer to any third party, or in any way commercially exploit any UBS research provided via Global Research or otherwise, and that you shall not extract data from any research or estimates provided to you via Global Research or otherwise, without the prior written consent of UBS.**

This document is for distribution only as may be permitted by law. It is not directed to, or intended for distribution to or use by, any person or entity who is a citizen or resident of or located in any locality, state, country or other jurisdiction where such distribution, publication, availability or use would be contrary to law or regulation or would subject UBS to any registration or licensing requirement within such jurisdiction. It is published solely for information purposes; it is not an advertisement nor is it a solicitation or an offer to buy or sell any financial instruments or to participate in any particular trading strategy. No representation or warranty, either expressed or implied, is provided in relation to the accuracy, completeness or reliability of the information contained in this document ("the Information"), except with respect to Information concerning UBS. The Information is not intended to be a complete statement or summary of the securities, markets or developments referred to in the document. UBS does not undertake to update or keep current the Information. Any opinions expressed in this document may change without notice and may differ or be contrary to opinions expressed by other business areas or groups of UBS. Any statements contained in this report attributed to a third party represent UBS's interpretation of the data, information and/or opinions provided by that third party either publicly or through a subscription service, and such use and interpretation have not been reviewed by the third party.

Nothing in this document constitutes a representation that any investment strategy or recommendation is suitable or appropriate to an investor's individual circumstances or otherwise constitutes a personal recommendation. Investments involve risks, and investors should exercise prudence and their own judgement in making their investment decisions. The financial instruments described in the document may not be eligible for sale in all jurisdictions or to certain categories of investors. Options, derivative products and futures are not suitable for all investors, and trading in these instruments is considered risky. Mortgage and asset-backed securities may involve a high degree of risk and may be highly volatile in response to fluctuations in interest rates or other market conditions. Foreign currency rates of exchange may adversely affect the value, price or income of any security or related instrument referred to in the document. For investment advice, trade execution or other enquiries, clients should contact their local sales representative.

The value of any investment or income may go down as well as up, and investors may not get back the full (or any) amount invested. Past performance is not necessarily a guide to future performance. Neither UBS nor any of its directors, employees or agents accepts any liability for any loss (including investment loss) or damage arising out of the use of all or any of the Information.

Any prices stated in this document are for information purposes only and do not represent valuations for individual securities or other financial instruments. There is no representation that any transaction can or could have been effected at those prices, and any prices do not necessarily reflect UBS's internal books and records or theoretical model-based valuations and may be based on certain assumptions. Different assumptions by UBS or any other source may yield substantially different results.

This document and the Information are produced by UBS as part of its research function and are provided to you solely for general background information. UBS has no regard to the specific investment objectives, financial situation or particular needs of any specific recipient. In no circumstances may this document or any of the Information be used for any of the following purposes:

(i) valuation or accounting purposes;

(ii) to determine the amounts due or payable, the price or the value of any financial instrument or financial contract; or

(iii) to measure the performance of any financial instrument.

By receiving this document and the Information you will be deemed to represent and warrant to UBS that you will not use this document or any of the Information for any of the above purposes or otherwise rely upon this document or any of the Information.

UBS has policies and procedures, which include, without limitation, independence policies and permanent information barriers, that are intended, and upon which UBS relies, to manage potential conflicts of interest and control the flow of information within divisions of UBS and among its subsidiaries, branches and affiliates. For further information on the ways in which UBS manages conflicts and maintains independence of its research products, historical performance information and certain additional disclosures concerning UBS research recommendations, please visit www.ubs.com/disclosures.

Research will initiate, update and cease coverage solely at the discretion of UBS Research Management, which will also have sole discretion on the timing and frequency of any published research product. The analysis contained in this document is based on numerous assumptions. All material information in relation to published research reports, such as valuation methodology, risk statements, underlying assumptions (including sensitivity analysis of those assumptions), ratings history etc. as required by the Market Abuse Regulation, can be found on NEO. Different assumptions could result in materially different results.

The analyst(s) responsible for the preparation of this document may interact with trading desk personnel, sales personnel and other parties for the purpose of gathering, applying and interpreting market information. UBS relies on information barriers to control the flow of information contained in one or more areas within UBS into other areas, units, groups or affiliates of UBS. The compensation of the analyst who prepared this document is determined exclusively by research management and senior management (not including investment banking). Analyst compensation is not based on investment banking revenues; however, compensation may relate to the revenues of UBS and/or its divisions as a whole, of which investment banking, sales and trading are a part, and UBS's subsidiaries, branches and affiliates as a whole.

For financial instruments admitted to trading on an EU regulated market: UBS AG, its affiliates or subsidiaries (excluding UBS Securities LLC) acts as a market maker or liquidity provider (in accordance with the interpretation of these terms in the UK) in the financial instruments of the issuer save that where the activity of liquidity provider is carried out in accordance with the definition given to it by the laws and regulations of any other EU jurisdictions, such information is separately disclosed in this document. For financial instruments admitted to trading on a non-EU regulated market: UBS may act as a market maker save that where this activity is carried out in the US in accordance with the definition given to it by the relevant laws and regulations, such activity will be specifically disclosed in this document. UBS may have issued a warrant the value of which is based on one or more of the financial instruments referred to in the document. UBS and its affiliates and employees may have long or short positions, trade as principal and buy and sell in instruments or derivatives identified herein; such transactions or positions may be inconsistent with the opinions expressed in this document.

**United Kingdom and the rest of Europe:** Except as otherwise specified herein, this material is distributed by UBS Limited to persons who are eligible counterparties or professional clients. UBS Limited is authorised by the Prudential Regulation Authority and regulated by the Financial Conduct Authority and the Prudential Regulation Authority. **France:** Prepared by UBS Limited and distributed by UBS Limited and UBS Securities France S.A. UBS Securities France S.A. is regulated by the ACPR (Autorité de Contrôle Prudentiel et de Résolution) and the Autorité des Marchés Financiers (AMF). Where an analyst of UBS Securities France S.A. has contributed to this document, the document is also deemed to have been prepared by UBS Securities France S.A. **Germany:** Prepared by UBS Limited and distributed by UBS Limited and UBS Europe SE. UBS Europe SE is regulated by the Bundesanstalt fur Finanzdienstleistungsaufsicht (BaFin). **Spain:** Prepared by UBS Limited and distributed by UBS Limited and UBS Securities España SV, SA. UBS Securities España SV, SA is regulated by the Comisión Nacional del Mercado de Valores (CNMV). **Turkey:** Distributed by UBS Limited. No information in this document is provided for the purpose of offering, marketing and sale by any means of any capital market instruments and services in the Republic of Turkey. Therefore, this document may not be considered as an offer made or to be made to residents of the Republic of Turkey. UBS AG is not licensed by the Turkish Capital Market Board under the provisions of the Capital Market Law (Law No. 6362). Accordingly, neither this document nor any other offering material related to the instruments/services may be utilized in connection with providing any capital market services to persons within the Republic of Turkey without the prior approval of the Capital Market Board. However, according to article 15 (d) (ii) of the Decree No. 32, there is no restriction on the purchase or sale of the securities abroad by residents of the Republic of Turkey. **Poland:** Distributed by UBS Limited (spolka z ograniczona odpowiedzialnoscia) Oddzial w Polsce regulated by the Polish Financial Supervision Authority. Where an analyst of UBS Limited (spolka z ograniczona odpowiedzialnoscia) Oddzial w Polsce has contributed to this document, the document is also deemed to have been prepared by UBS Limited (spolka z ograniczona odpowiedzialnoscia) Oddzial w Polsce. **Russia:** Prepared and distributed by UBS Bank (OOO). **Switzerland:** Distributed by UBS AG to persons who are institutional investors only. UBS AG is regulated by the Swiss Financial Market Supervisory Authority (FINMA). **Italy:** Prepared by UBS Limited and distributed by UBS Limited and UBS Limited, Italy Branch. Where an analyst of UBS Limited, Italy Branch has contributed to this document, the document is also deemed to have been prepared by UBS Limited, Italy Branch. **South Africa:** Distributed by UBS South Africa (Pty) Limited (Registration No. 1995/011140/07), an authorised user of the JSE and an authorised Financial Services Provider (FSP 7328). **Israel:** This material is distributed by UBS Limited. UBS Limited is authorised by the Prudential Regulation Authority and regulated by the Financial Conduct Authority and the Prudential Regulation Authority. UBS Securities Israel Ltd is a licensed Investment Marketer that is supervised by the Israel Securities Authority (ISA). UBS Limited and its affiliates incorporated outside Israel are not licensed under the Israeli Advisory Law. UBS Limited is not covered by insurance as required from a licensee under the Israeli Advisory Law. UBS may engage among others in issuance of Financial Assets or in distribution of Financial Assets of other issuers for fees or other benefits. UBS Limited and its affiliates may prefer various Financial Assets to which they have or may have Affiliation (as such term is defined under the Israeli Advisory Law). Nothing in this Material should be considered as investment advice under the Israeli Advisory Law. This Material is being issued only to and/or is directed only at persons who are Eligible Clients within the meaning of the Israeli Advisory Law, and this material must not be relied on or acted upon by any other persons. **Saudi Arabia:** This document has been issued by UBS AG (and/or any of its subsidiaries, branches or affiliates), a public company limited by shares, incorporated in Switzerland with its registered offices at Aeschenvorstadt 1, CH-4051 Basel and Bahnhofstrasse 45, CH-8001 Zurich. This publication has been approved by UBS Saudi Arabia (a subsidiary of UBS AG), a Saudi closed joint stock company incorporated in the Kingdom of Saudi Arabia under commercial register number 1010257812 having its registered office at Tatweer Towers, P.O. Box 75724, Riyadh 11588, Kingdom of Saudi Arabia. UBS Saudi Arabia is authorized and regulated by the Capital Market Authority to conduct securities business under license number 08113-37. **Dubai:** The information distributed by UBS AG Dubai Branch is intended for Professional Clients only and is not for further distribution within the United Arab Emirates. **United States:** Distributed to US persons by either UBS Securities LLC or by UBS Financial Services Inc., subsidiaries of UBS AG; or by a group, subsidiary or affiliate of UBS AG that is not registered as a US broker-dealer (a **'non-US affiliate'** ) to major US institutional investors only. UBS Securities LLC or UBS Financial Services Inc. accepts responsibility for the content of a document prepared by another non-US affiliate when distributed to US persons by UBS Securities LLC or UBS Financial Services Inc. All transactions by a US person in the securities mentioned in this document must be effected through UBS Securities LLC or UBS Financial Services Inc., and not through a non-US affiliate. UBS Securities LLC is not acting as a municipal advisor to any municipal entity or obligated person within the meaning of Section 15B of the Securities Exchange Act (the "Municipal Advisor Rule"), and the opinions or views contained herein are not intended to be, and do not constitute, advice within the meaning of the Municipal Advisor Rule. **Canada:** Distributed by UBS Securities Canada Inc., a registered investment dealer in Canada and a Member-Canadian Investor Protection Fund, or by another affiliate of UBS AG that is registered to conduct business in Canada or is otherwise exempt from registration. **Mexico:** This report has been distributed and prepared by UBS Casa de Bolsa, S.A. de C.V., UBS Grupo Financiero, an entity that is part of UBS Grupo Financiero, S.A. de C.V. and is an affiliate of UBS AG. This document is intended for distribution to institutional or sophisticated investors only. Research reports only reflect the views of the analysts responsible for the reports. Analysts do not receive any compensation from persons or entities different from UBS Casa de Bolsa, S.A. de C.V., UBS Grupo Financiero, or different from entities belonging to the same financial group or business group of such. For Spanish translations of applicable disclosures, please see www.ubs.com/disclosures. **Brazil:** Except as otherwise specified herein, this material is prepared by UBS Brasil CCTVM S.A. to persons who are eligible investors residing in Brazil, which are considered to be: (i) financial institutions, (ii) insurance firms and investment capital companies, (iii) supplementary pension entities, (iv) entities that hold financial investments higher than R$300,000.00 and that confirm the status of qualified investors in written, (v) investment funds, (vi) securities portfolio managers and securities consultants duly authorized by Comissão de Valores Mobiliários (CVM), regarding their own investments, and (vii) social security systems created by the Federal Government, States, and Municipalities. **Hong Kong:** Distributed by UBS Securities Asia Limited and/or UBS AG, Hong Kong Branch. **Singapore:** Distributed by UBS Securities Pte. Ltd. [MCI (P) 007/09/2016 and Co. Reg. No.: 198500648C] or UBS AG, Singapore Branch. Please contact UBS Securities Pte. Ltd., an exempt financial adviser under the Singapore Financial Advisers Act (Cap. 110); or UBS AG, Singapore Branch, an exempt financial adviser under the Singapore Financial Advisers Act (Cap. 110) and a wholesale bank licensed under the Singapore Banking Act (Cap. 19) regulated by the Monetary Authority of Singapore, in respect of any matters arising from, or in connection with, the analysis or document. The recipients of this document represent and warrant that they are accredited and institutional investors as defined in the Securities and Futures Act (Cap. 289). **Japan:** Distributed by UBS Securities Japan Co., Ltd. to professional investors (except as otherwise permitted). Where this document has been prepared by UBS Securities Japan Co., Ltd., UBS Securities Japan Co., Ltd. is the author, publisher and distributor of the document. Distributed by UBS AG, Tokyo Branch to Professional Investors (except as otherwise permitted) in relation to foreign exchange and other banking businesses when relevant. **Australia:** Clients of UBS AG: Distributed by UBS AG (ABN 47 088 129 613 and holder of Australian Financial Services License No. 231087). Clients of UBS Securities Australia Ltd: Distributed by UBS Securities Australia Ltd (ABN 62 008 586 481 and holder of Australian Financial Services License No. 231098). This Document contains general information and/or general advice only and does not constitute personal financial product advice. As such, the Information in this document has been prepared without taking into account any investor's objectives, financial situation or needs, and investors should, before acting on the Information, consider the appropriateness of the Information, having regard to their objectives, financial situation and needs. If the Information contained in this document relates to the acquisition, or potential acquisition of a particular financial product by a 'Retail' client as defined by section 761G of the Corporations Act 2001 where a Product Disclosure Statement would be required, the retail client should obtain and consider the Product Disclosure Statement relating to the product before making any decision about whether to acquire the product. The UBS Securities Australia Limited Financial Services Guide is available at: www.ubs.com/ecs-research-fsg. **New Zealand:** Distributed by UBS New Zealand Ltd. UBS New Zealand Ltd is not a registered bank in New Zealand. You are being provided with this UBS publication or material because you have indicated to UBS that you are a "wholesale client" within the meaning of section 5C of the Financial Advisers Act 2008 of New Zealand (Permitted Client). This publication or material is not intended for clients who are not Permitted Clients (non-permitted Clients). If you are a non-permitted Client you must not rely on this publication or material. If despite this warning you nevertheless rely on this publication or material, you hereby (i) acknowledge that you may not rely on the content of this publication or material and that any recommendations or opinions in such this publication or material are not made or provided to you, and (ii) to the maximum extent permitted by law (a) indemnify UBS and its associates or related entities (and their respective Directors, officers, agents and Advisors) (each a 'Relevant Person') for any loss, damage, liability or claim any of them may incur or suffer as a result of, or in connection with, your unauthorised reliance on this publication or material and (b) waive any rights or remedies you may have against any Relevant Person for (or in respect of) any loss, damage, liability or claim you may incur or suffer as a result of, or in connection with, your unauthorised reliance on this publication or material. **Korea:** Distributed in Korea by UBS Securities Pte. Ltd., Seoul Branch. This document may have been edited or contributed to from time to time by affiliates of UBS Securities Pte. Ltd., Seoul Branch. **Malaysia:** This material is authorized to be distributed in Malaysia by UBS Securities Malaysia Sdn. Bhd (Capital Markets Services License No.: CMSL/A0063/2007). This material is intended for professional/institutional clients only and not for distribution to any retail clients. **India:** Distributed by UBS Securities India Private Ltd. (Corporate Identity Number U67120MH1996PTC097299) 2/F, 2 North Avenue, Maker Maxity, Bandra Kurla Complex, Bandra (East), Mumbai (India) 400051. Phone: +912261556000. It provides brokerage services bearing SEBI Registration Numbers: NSE (Capital Market Segment): INB230951431, NSE (F&O Segment) INF230951431, NSE (Currency Derivatives Segment) INE230951431, BSE (Capital Market Segment) INB010951437; merchant banking services bearing SEBI Registration Number: INM000010809 and Research Analyst services bearing SEBI Registration Number: INH000001204. UBS AG, its affiliates or subsidiaries may have debt holdings or positions in the subject Indian company/companies. Within the past 12 months, UBS AG, its affiliates or subsidiaries may have received compensation for non-investment banking securities-related services and/or non-securities services from the subject Indian company/companies. The subject company/companies may have been a client/clients of UBS AG, its affiliates or subsidiaries during the 12 months preceding the date of distribution of the research report with respect to investment banking and/or non-investment banking securities-related services and/or non-securities services. With regard to information on associates, please refer to the Annual Report at: http://www.ubs.com/global/en/about_ubs/investor_relations/annualreporting.html

The disclosures contained in research documents produced by UBS Limited shall be governed by and construed in accordance with English law.