Quantessentials

R advice – getting started with random forests

Equities

Global Quantitative

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

Paul Winter
Analyst
paul-j.winter@ubs.com
+61-2-9324 2080

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

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

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

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

Pieter Stoltz
Analyst
pieter.stoltz@ubs.com
+61-2-9324 3779

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

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

Continuing Quantessentials

By popular demand we continue our Quantessentials series, aimed at educating clients to the technical aspects of our research and exploring real-world implementation issues.

A popular general-purpose technique

In this report we introduce some implementation details of random forests, following several highly popular reports on their application to stock selection, style timing and forecasting dividend cuts. They present an attractive tool for general purpose modelling owing to their performance, simplicity and robustness to over-fitting.

Everything you need to know to get started

We provide a guided walkthrough of the random forests technique as applied to a real-world financial data set. We explain how to prepare the input data, how to predict using the model, how to interpret the internal workings and how to tune the algorithm to achieve the best results.

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A novel technique

There are many, many choices of machine learning algorithms available currently. Naturally there is no single best choice for all situations; however random forests present a very compelling offering:

- excellent predictive performance
- easy to understand
- does not over-fit

In short, the way this algorithm works is by computing thousands of randomly permuted decision trees, then taking the consensus amongst them. This is a powerful approach to modern data analysis, only made possible by an explosion in computational resources—and quite distinct from the more traditional reductive modelling common to financial literature[1].

Although the advances in deep learning are breaking new ground on some of the most challenging problems in computer vision and natural language processing, random forests present an excellent general purpose tool to quickly explore and model new problems with.

Implementations

The popular choices

The reference implementation is the randomForest package, which is ported from the Fortran code from the random forests authors Leo Brieman and Adele Cutler. A popular alternative is the party package, which adopts the conditional inference trees introduced in Hothorn (2006)—our package of choice.

Larger problems

Larger modelling problems can use the fast C++implementations from the Rborist or ranger packages. A parallelised version for survival, regression and classification problems is the randomForestSRC package; ggRandomForests provides a graphical utility package for this. Another package called bigrf was available but has since been removed from the CRAN due to quality problems.

Other problems

The predecessor to random forests are classification and regression trees (CART), available in the package rpart. Methods for bootstrap aggregation (bagging) are available in ipred, but this package suggests the randomForest or party packages. The missForest and mixRF packages adopt random forests for imputing data.

A handful of other packages implement random forests for specific problems, e.g. quantile regression (quantregForest) or logic regression (LogicReg). Using random forests for variable selection is quite popular; see the varSelRF, Boruta, RFgroove, and AUCRF packages.

[1] For further details, refer to our Jan 2015 note (Stock selection using Machine Learning).

Getting started

Preparing data

Typically the first and most laborious step of any modelling problem is cleaning the input data. Fortunately, random forests are robust to outliers in the input space, making this relatively painless—however missing values still need to be "plugged".

Missing values first need to be plugged (imputed)

There are two simple ways of achieving this with the *randomForest* package. The function *na.roughfix* simply imputes the column median; alternatively, the *rfImpute* function imputes missing values according to their similarity to other observations.

We introduce a simple data set containing 40 of the largest companies and several quantitative factors in the appendix. Of course, in practice our models are trained on trailing data then applied to the latest factor data to form predictions; here we predict in-sample since such a tiny data set has limited predictive power anyway.

See the Appendix for the data set before running the examples

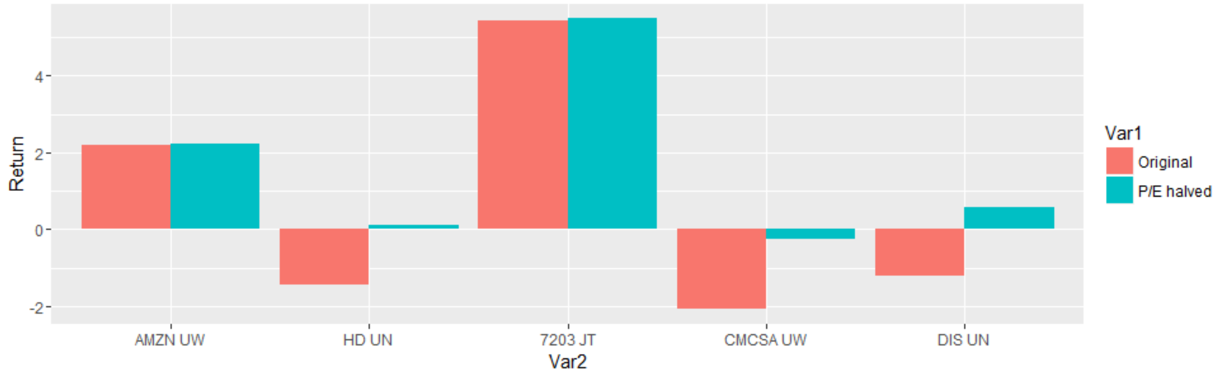
Predicting

Prediction is straightforward as most packages implement the standard interfaces. Figure 1 shows the expected return impact of halving the P/E in the consumer discretionary names. Interestingly the expected returns increase in all cases but much less so for AMZN US and 7203 JT, which trade near the expensive and cheap extremes of this data set—thus capturing powerful non-linear effects.

Run the examples in order!

Figure 1: Predicting with random forests

```
require(randomForest)
require(ggplot2)
require(reshape2)
stop('see appendix for the data set used')

# impute missing values using the forward return as the response, and grow the forest
data <- rfImpute(FwdReturn~., data)
rf <- randomForest(FwdReturn~., data=data, ntree=1000)

# grab the consumer discretionary names
x <- data[data$Sector == 'Consumer Discretionary', ]

# the fitted returns for comparison
z <- predict(rf, x)

# now imagine the valuations half but everything else stays the same
x$PE <- x$PE * 0.5
y <- predict(rf, x)

ggplot(melt(rbind('Original'=z, 'P/E halved'=y), value.name='Return'),
  aes(Var2, Return, fill=Var1)) + geom_bar(stat='identity', position='dodge')
```



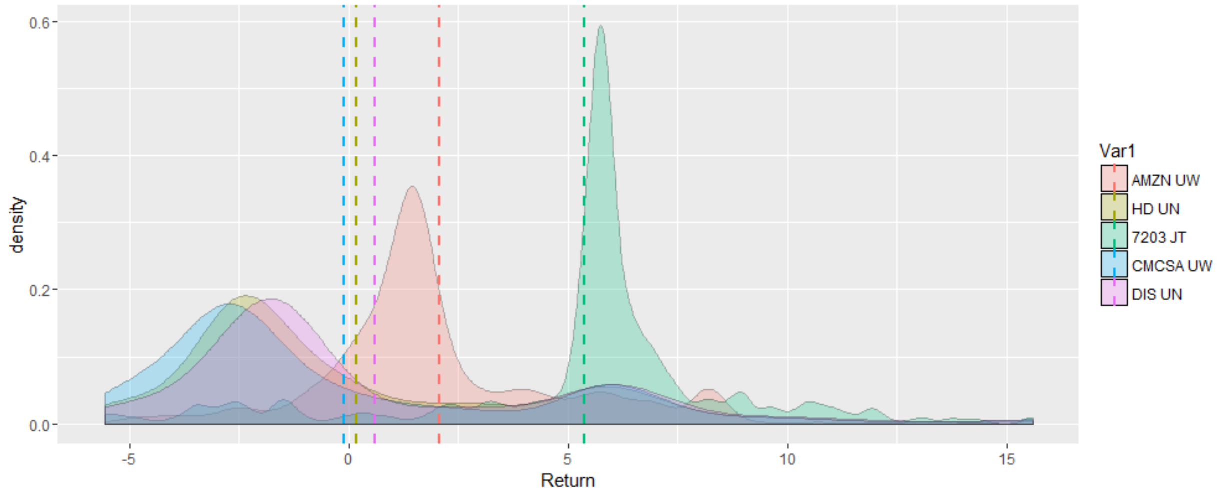
Source: UBS Quant

Looking under the hood

A common criticism of ensemble techniques is that they are regarded as "black boxes". However, there are several tools available to illuminate the underlying mechanics of random forests. Firstly, the distribution of the individual estimates can easily be visualised, as in Figure 2 below. The predictions are simply the average of these individual estimates, illustrated by the vertical dashed lines.

Figure 2: Visualising the individual forest densities

```
require(data.table)

# predict again, and include the invidual tree estimates
y <- predict(rf, x, predict.all=T)

# put the individual estimates in a long format
z <- data.table(melt(y$individual, value.name='Return'))

# predict(rf, x) is just the equal-weighted average across the trees
z[, mean(Return), by=Var1]

# plot the density of the predictions in the forest
ggplot(z, aes(x=Return, fill=Var1)) + geom_density(alpha=0.25) +
  geom_vline(data=z[, mean(Return), by=Var1], aes(xintercept=V1,  colour=Var1),
  linetype="dashed", size=1)
```



Source: UBS Quant

This technique was used to estimate the stock-level forecast return distribution in our research paper on behavioural finance (link), in which we then transformed these return distributions by the empirically observed behaviours formalised by cumulative prospect theory.

Variable importance

From above, we note the predictions are the consensus of the individual estimates, and so we cannot dissect predictions into their respective "loadings" on individual factors as in a linear regression.

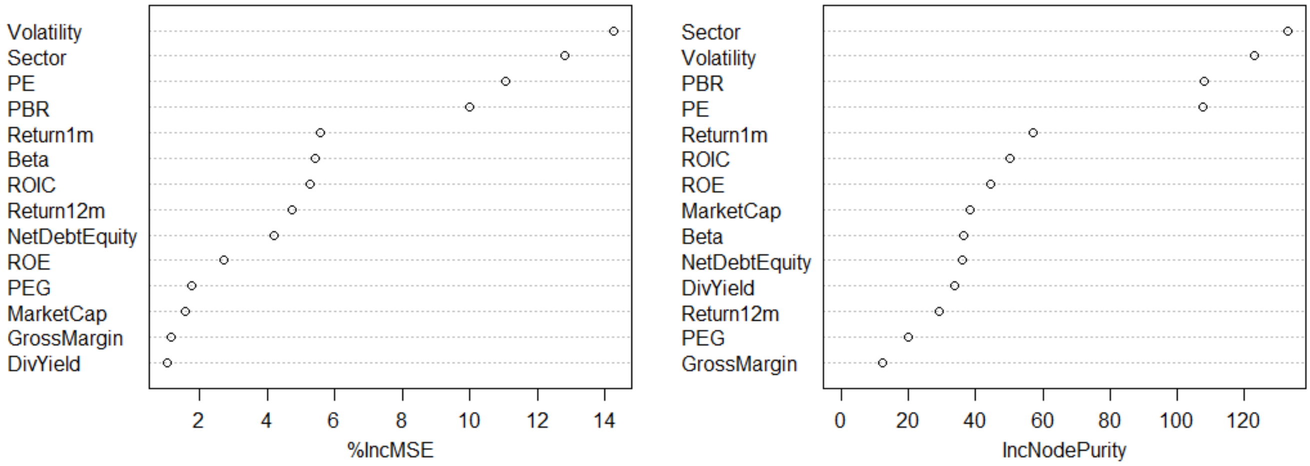
Which factors are important to the random forest model?

However, we can still show which factors are important in the model. One method for showing this is by considering the average "improvement" of the model before and after the factor is chosen for a split (the right chart in Figure 3).

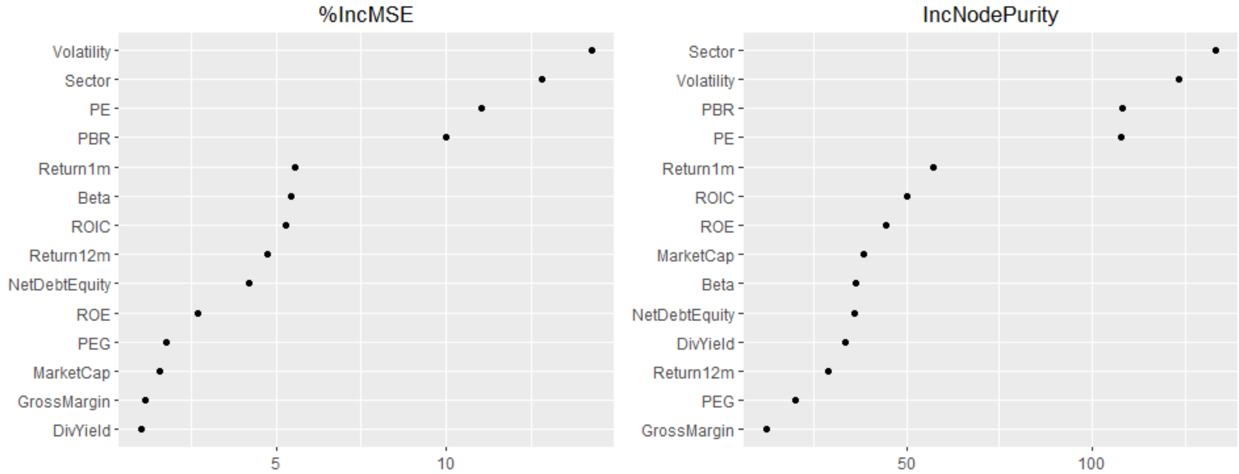
A more common method involves predicting with the model, observing the error rate, then randomising the factor and observing the subsequent degradation in the model performance, for each factor in turn (left chart in Figure 3). The results of these two methods often coincide and are useful for variable selection (choosing which variables in a problem to keep).

Figure 3: Variable importance

```
# you need to run with importance=T, to get the change in error
rf <- randomForest(FwdReturn~., data=data, ntree=1000, importance=T, proximity=T)
varImpPlot(rf)
```




```
# you can also extract the variable importance directly like this
imp <- data.table(melt(importance(rf)))

# and produce a similar plot to above
require(gridExtra)
imp <- lapply(levels(imp[, Var2]), function(l) { ggplot(imp[Var2==l]) +
  geom_point(aes(reorder(Var1, value), value)) + ggtitle(l) + coord_flip() +
  theme(axis.title.x=element_blank()) + theme(axis.title.y=element_blank()) })

do.call(grid.arrange, c(imp, ncol=2))
```



Source: UBS Quant

Proximities

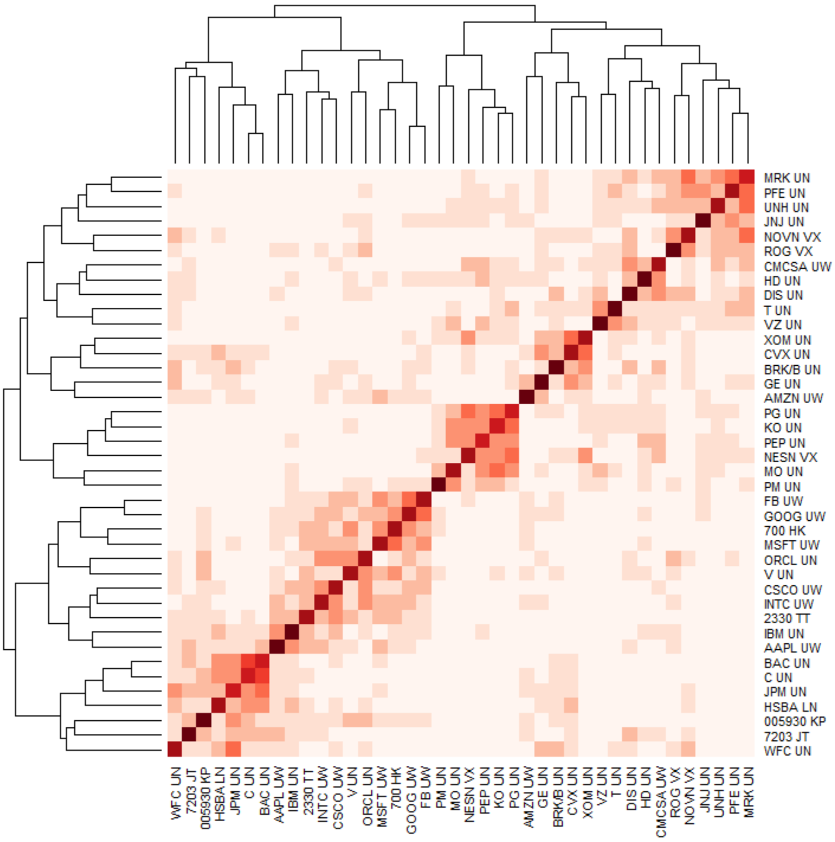
Another helpful output of the random forest algorithm is the "proximities", the measure of how often the data points are lumped together in the same leaf nodes, on average. This gives an indication as to how similar the data points look; in that their responses are assumed to be meaningfully grouped. These are interesting for clustering, visualisation and imputation, to name a few applications.

A neat measure of similarity; measured by how often the observations are lumped together

Figure 4 shows a simple heatmap of these proximities, in which several clusters of companies can be seen. The block structures in this can be identified as clusters of technology, consumer, conglomerates, pharmaceutical, financial stocks, and so on.

Figure 4: Visualising proximities

```
require(RColorBrewer)
pal <- brewer.pal(9, 'Reds')
heatmap(rf$proximity, col=pal)
```




```
# proximities are also useful for weighted imputation, e.g. for Johnson & Johnson
i <- which(rownames(data)=='JNJ UN')
weighted.mean(data$Beta[-i], rf$proximity[-i, i])

# which is essentially what rfImpute() does, for multiple missing observations at once
i <- which(data$Sector=='Consumer Staples')
data$Beta[-i] %*% rf$proximity[-i, i] / colSums(rf$proximity[-i, i])
```

Source: UBS Quant

Tuning

The number of trees in the forest (ntrees)

One of the most attractive aspects of random forests is that they need very little tuning to deliver competitive results "out of the box". There are two parameters to tune: the number of trees in the forest (*ntrees*), and the number of variables to use at each split (*mtry*). Below we show the effect of these on predictions and suggest guidelines for choosing their values.

Random forests deliver excellent performance with little effort required

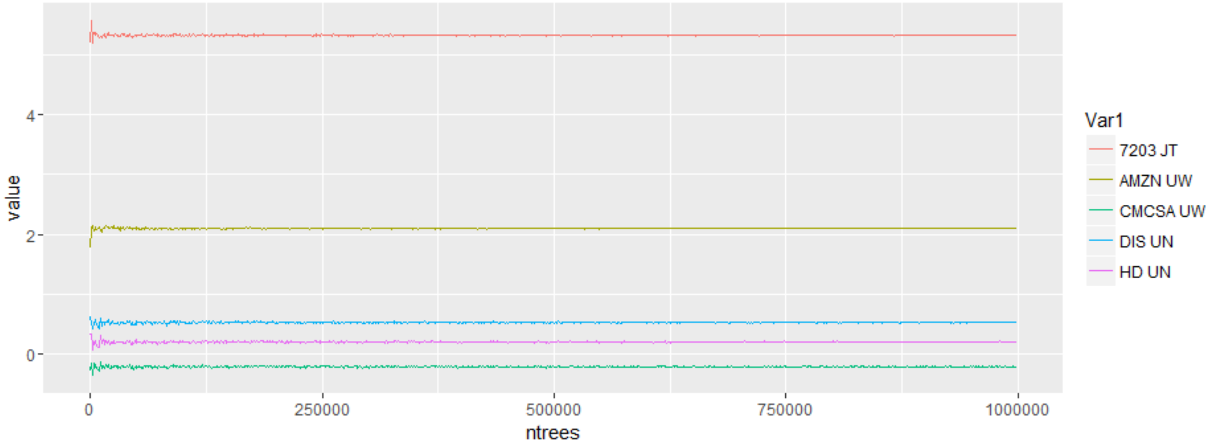
The *ntrees* parameter should be made as large as computationally feasible; there is no downside to making this arbitrarily large. Naturally there is decreasing marginal benefit to increasing this; there will likely be little difference between ten thousand trees and ten million trees. Many implementations default to 500 trees, however this is too small for our toy data set in this case.

The *ntrees* parameter should be made as large as computationally feasible

Figure 5 shows the effect of this parameter on individual return predictions; clearly the estimates stabilise early through the results, even on this tiny data set.

Figure 5: The effect of the "ntrees" parameter on predictions

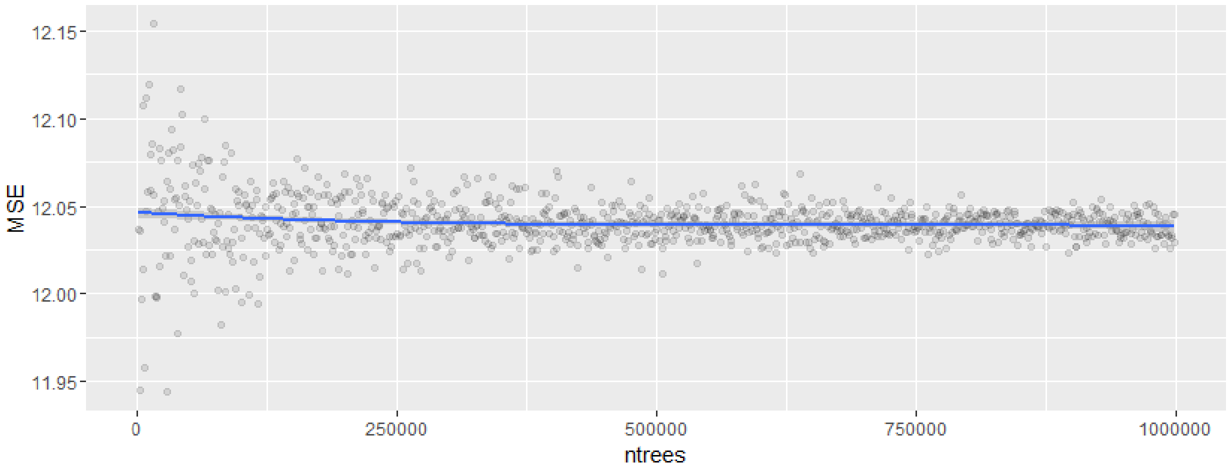
```
# run the randomforest model using these parameters
# the graphs were built using seq(1e2, 1e6, 1e3), but it's quite slow to run
ntrees <- seq(1e2, 1e6, 1e5)

paramtest <- rbindlist(lapply(ntrees, function(n) {
  rf <- randomForest(FwdReturn~., data=data, ntree=n)
  pred <- predict(rf, x)
  data.table(melt(pred))[, `:=`(Var1=rownames(x), ntrees=n)]
}))

# the predictions converge fairly quickly
ggplot() + geom_line(data=paramtest, aes(ntrees, value, factor=Var1, colour=Var1))
```



Source: UBS Quant

Figure 6: The effect of the "ntrees" parameter on the error

```
nt <- rbindlist(lapply(ntrees, function(n) {
  rf <- randomForest(FwdReturn~., data=data, ntree=n)
  data.table(ntrees=n, MSE=tail(rf$mse, 1))
}))

ggplot(nt[ntrees>100], aes(ntrees, MSE)) + geom_point(alpha=0.1) + geom_smooth()
```

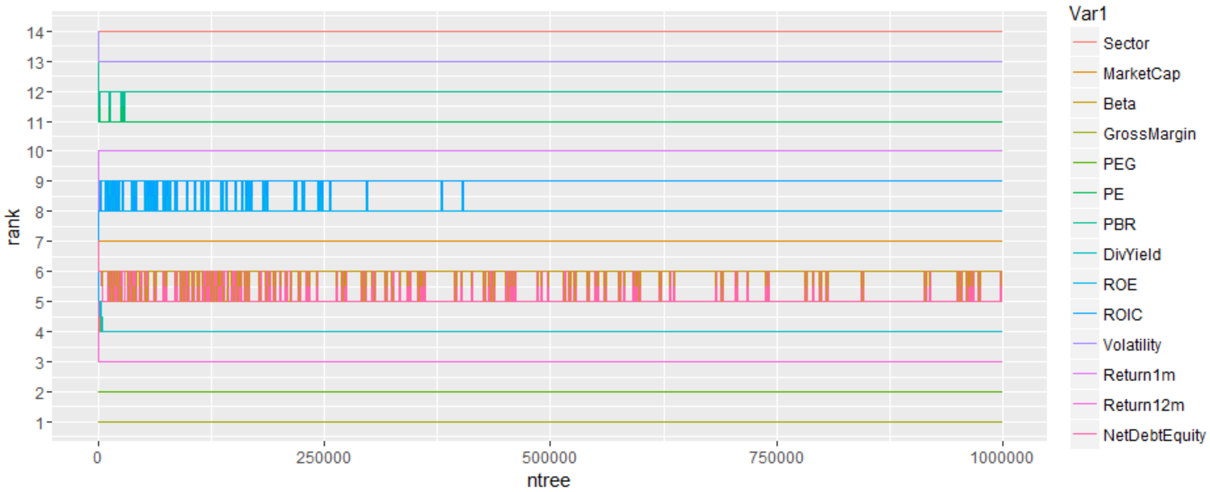


Source: UBS Quant

Strobl (2008) suggests setting *ntrees* high enough to preserve the ordering of the variable importance. Figure 7 shows how to calculate and visualise this using a parallel coordinate plot of the variable importance ranks, as a function of *ntrees*. Naturally on a larger data set, these rankings are expected to stabilise earlier.

Figure 7: Variable importance ordering vs the number of trees

```
# use as many trees as necessary to preserve variable importance ordering
imptest <- rbindlist(lapply(ntrees, function(n) {
  rf <- randomForest(FwdReturn~., data=data, ntree=n, importance=T)
  imp <- data.table(melt(importance(rf, type=1)))
  imp[, `:=`(ntree=n, rank=rank(value))]
  imp
}))

# but this data set is tiny and probably won't converge regardless of ntrees
ggplot(imptest) + geom_line(aes(ntree, rank, group=Var1, color=Var1)) +
scale_y_continuous(breaks=seq(ncol(data)))
```



Source: UBS Quant

The number of splitting variables (mtry)

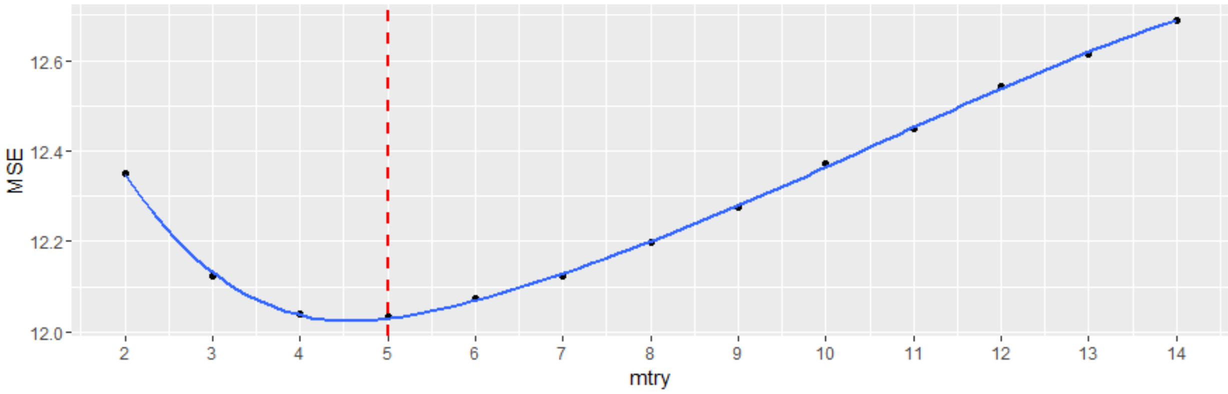
This parameter is context dependent and should be given careful consideration in tuning. Consider the extremes of this parameter: if the number of factors to split on is too small then the individual trees simply have too little data to work with and produce poor results, the average of which will still be poor. Conversely if the number of factors is too large, the individual trees will all look similar and there will be no diversity in the ensemble—again leading to poor results.

This parameter introduces a trade-off and should be carefully considered

Naturally we expect the optimal value lies somewhere between these extremes; below we show the optimal level for our data set. The *tuneRF* function from the *randomForest* package can also tune this parameter. A data set with m columns uses a default mtry of $\sqrt{m}$ for classification and $\lfloor m/3 \rfloor$ for regression.

Figure 8: The number of splitting variables (mtry) vs the error rate (MSE)

```
mtry <- seq(2, ncol(data)-1)
mtrytest <- rbindlist(lapply(mtry, function(m) {
  rf <- randomForest(FwdReturn~., data=data, ntree=1e6, mtry=m)
  data.table(mtry=m, MSE=tail(rf$mse, 1))
}))

ggplot(mtrytest, aes(mtry, MSE)) + geom_point() +
    scale_x_continuous(breaks=mtry) + geom_smooth(se=F) +
    geom_vline(data=mtrytest[which.min(mtrytest$MSE), ],
    aes(xintercept=mtry), linetype="dashed", size=1, colour='red')
```



Source: UBS Quant

Conditional inference

Our earlier work on random forests uses the conditional inference forests from the party package, which uses statistically motivated criterion to grow the trees rather than the deterministic approach of the original method. This was found to improve performance and produced an unbiased measure of variable importance in the presence of real-world data limitations: highly varied measurement scales, unique levels and missing values.

Figure 9: Predicting using the "party" package

```
require(party)

# leave the other control parameters untouched unless there's a good reason to change them!
cf <- cforest(FwdReturn~., data=data, control=cforest_unbiased(ntree=1e6, mtry=4))

# otherwise the interface is largely consistent
predict(cf, x, OOB=T)
```

Source: UBS Quant

Appendix

In Figure 10 below we show the data set used in this report. Copy and paste this directly into R before working through the examples. This includes 40 of the largest companies globally and a handful of common factors used in quantitative analysis. The factors are as of 31st July 2016 and the forward return includes up to 31st August 2016.

Figure 10: The data set used in the report

```
data <- read.csv(row.names=1,
text="Ticker,Sector,MarketCap,Beta,GrossMargin,PEG,PE,PBR,DivYield,ROE,ROIC,Volatility,FwdReturn,Return1m,Return12m,NetD
ebtEquity
AAPL UW,Information Technology,562022,1.38,38.80,2.12,11.84,4.38,2.00,39.06,27.47,21.97,2.36,11.49,-13.70,0.19
MSFT UW,Information Technology,442557,1.23,62.66,NA,19.39,5.96,2.36,12.34,8.72,22.65,2.01,13.69,27.42,-0.79
XOM UN,Energy,368876,0.82,21.54,NA,24.26,2.14,3.28,7.58,6.63,13.99,-1.18,-0.78,13.34,0.22
JNJ UN,Health Care,344596,0.75,69.43,0.20,18.06,4.74,2.40,21.89,17.51,9.79,-4.07,5.27,29.44,-0.23
AMZN UW,Consumer Discretionary,359676,1.34,33.48,0.00,91.71,24.27,0.00,9.10,4.35,27.04,1.36,6.31,43.07,0.10
GE UN,Industrials,279053,1.02,34.08,0.03,19.02,3.14,2.95,8.33,2.72,17.84,0.32,4.38,23.61,1.22
FB UW,Information Technology,355708,1.17,83.88,0.47,27.29,7.52,0.00,11.02,11.01,17.89,1.76,10.91,31.18,-0.44
NESN VX,Consumer Staples,250209,0.78,49.62,NA,22.10,3.84,2.90,13.69,11.59,13.88,0.77,5.11,10.82,0.24
T UN,Telecommunication Services,266320,0.46,38.60,NA,14.68,2.16,4.39,13.19,6.59,11.39,-5.57,2.46,30.59,0.98
JPM UN,Financials,231060,1.25,NA,0.51,10.71,1.04,2.75,9.69,4.09,24.89,5.52,8.54,-3.00,2.27
WFC UN,Financials,242176,1.07,NA,0.94,11.59,1.40,3.13,11.75,5.69,20.34,6.75,4.40,-13.69,1.82
GOOG UW,Information Technology,527988,1.21,61.78,0.40,20.29,4.27,0.00,14.24,13.93,16.61,-0.23,9.69,18.78,-0.57
PG UN,Consumer Staples,228360,0.60,50.23,NA,21.47,3.92,3.11,14.03,10.80,11.36,2.01,3.66,9.32,0.33
PFE UN,Health Care,223762,0.61,72.03,0.09,14.45,3.55,3.09,11.65,8.10,12.78,-4.86,6.48,7.43,0.32
VZ UN,Telecommunication Services,225851,0.60,47.56,2.26,13.93,12.12,4.05,128.45,14.94,12.93,-5.56,1.08,25.13,5.58
CVX UN,Energy,193144,1.23,8.07,NA,30.39,1.28,4.18,0.85,0.70,16.28,-0.83,0.16,15.52,0.22
NOVN VX,Health Care,197850,1.09,64.35,NA,16.84,2.78,3.36,9.13,7.54,18.76,-3.61,3.68,-15.70,0.32
BRK/B UN,Financials,355729,0.88,24.96,1.22,18.60,1.38,0.00,9.80,7.20,15.94,4.31,2.95,0.84,0.17
KO UN,Consumer Staples,188263,0.57,59.90,NA,22.08,7.59,3.07,27.08,13.62,13.52,-0.46,-1.20,11.11,0.99
MRK UN,Health Care,162462,0.82,62.81,0.71,15.67,3.71,3.10,10.08,6.56,16.40,7.04,5.13,5.11,0.29
ROG VX,Health Care,218243,1.04,69.34,0.02,15.97,10.05,3.27,43.70,23.02,20.07,-3.11,-0.28,-8.42,0.66
HD UN,Consumer Discretionary,170865,1.06,32.27,0.91,20.51,27.17,1.78,93.09,28.78,15.99,-2.48,8.18,22.59,2.79
INTC UW,Information Technology,164400,1.41,62.20,0.12,13.30,2.69,2.81,19.46,15.12,21.46,3.74,11.48,24.05,0.17
BAC UN,Financials,148041,1.46,NA,NA,10.19,0.63,1.38,6.18,3.22,33.22,11.90,15.59,-16.82,1.12
7203 JT,Consumer Discretionary,173183,0.94,20.05,5.23,10.57,1.07,3.56,13.60,8.60,33.75,5.84,17.77,-25.12,0.76
CMCSA UW,Consumer Discretionary,162195,0.69,58.39,0.99,17.97,3.10,1.52,15.72,8.27,13.67,-2.96,8.05,10.63,0.95
CSCO UW,Information Technology,153688,1.37,62.51,0.63,12.52,2.46,2.92,16.91,12.63,19.58,2.98,10.83,11.97,-0.56
V UN,Information Technology,184419,0.93,78.23,0.91,24.14,5.81,0.67,23.85,18.68,21.15,3.83,5.36,6.71,-0.17
PM UN,Consumer Staples,155536,0.72,64.38,0.03,21.19,NA,4.05,NA,50.88,16.76,-0.33,0.57,21.11,-2.11
PEP UN,Consumer Staples,156954,0.62,54.91,NA,21.84,13.99,2.58,38.27,12.83,12.88,-1.30,5.86,15.84,2.04
005930 KP,Information Technology,194464,0.99,37.45,0.54,9.58,1.28,1.36,11.65,11.54,21.70,5.26,7.80,24.56,-0.36
700 HK,Information Technology,226081,0.96,58.39,0.62,31.22,11.53,0.25,28.87,19.78,23.56,8.20,10.85,29.39,-0.83
DIS UN,Consumer Discretionary,163115,1.06,41.35,1.08,15.75,3.70,1.43,20.22,15.49,15.01,-1.55,0.57,-17.93,0.37
HSBA LN,Financials,130240,1.19,NA,NA,11.19,0.73,6.91,6.44,3.34,19.57,15.59,10.66,-7.94,0.22
IBM UN,Information Technology,153528,0.96,48.76,0.18,11.59,10.33,3.24,95.80,25.52,18.82,-0.23,10.75,4.66,2.06
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MO UN,Consumer Staples,132286,0.46,62.41,0.31,21.00,48.25,3.27,205.76,35.00,11.90,-2.38,-1.18,26.19,3.29
UNH UN,Health Care,136613,0.83,NA,0.34,16.68,3.88,1.40,17.93,10.94,13.06,-4.99,2.92,19.52,0.66")
```

Source: UBS Quant

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UBS Equity Quantitative Research team

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	
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/China

Josh Holcroft	+852 2971 7705
Shanle Wu	+852 2971 7513
Cathy Fang	+86 021 38668891

Australia

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

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