Quantessentials

A quick tutorial in 'nowcasting'

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By popular demand we continue our Quantessentials series that aims to educate clients in the technical aspects of our research and explore real-world implementation issues.

An increasingly common problem

Nowcasting essentially refers to the task of predicting the present (or thereabouts). This generally involves combining higher frequency timeseries to make a forecast of a lower frequency variable of primary interest. While this is by no means a new problem, it has become increasingly popular over recent history; perhaps due to the explosion in data availability and computing power.

A valuable addition to the investor toolkit

We believe that working knowledge of these techniques is an importation addition to the investor's toolkit. Fortunately, the technological democratisation underway means that many such solutions to this problem are readily available; this report introduces one such technique, known as the MIDAS regression.

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A common problem

For readers unfamiliar with the term, "nowcasting" refers to the task of predicting the present (or thereabouts). Such a task often arises in econometrics, in which key indicators like GDP are typically infrequently published, often with a significant lag and even then, subject to data revisions retroactively.

Nowcasting = predicting the present (or thereabouts)

However many components of GDP e.g. industrial production, or indeed any other correlated predictors, are often published in a timelier and more frequent fashion; nowcasting is essentially the task of combining such higher frequency timeseries to make a forecast of the low frequency variable of primary interest. While this is by no means a new problem, it has become increasingly popular over recent history; perhaps due to the explosion in data availability and computing power.

We believe that working knowledge of these techniques is an importation addition to the investor's toolkit. Fortunately, many solutions to this problem are readily available to investors already; this report introduces one such technique, known as the MIDAS regression.

We believe that working knowledge of these techniques is a valuable investor tool

Approaches

There are many different ways of tackling the problem of nowcasting, all of which naturally have their relative benefits. We omit the technical details here, rather we intend to introduce these techniques and highlight useful implementation tips we have found. Refer to the appendix for further references in the literature.

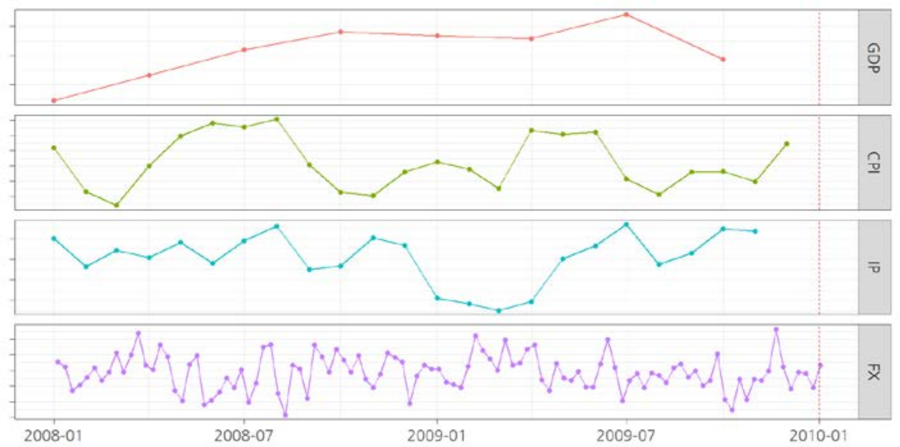
Temporal aggregation

The simplest approach to regressing, say a quarterly GDP series against a monthly industrial production series, is to simply aggregate the monthly figure up to the quarterly frequency. Obviously this aggregation depends on the stock-flow nature of the high frequency variables used, e.g. whether we are considering the number of people unemployed, or the change thereof.

The simplest approach is just to aggregate the data to the same frequency

This approach of course has the key weakness of requiring that an entire period of the high frequency data is available before a low-frequency estimate can be made; when multiple components are incorporated into a time series, this imbalance in the contemporaneous data availability is referred to as a "ragged edge".

Figure 1: The ragged edge of mixed frequency data (illustrative data)



Source: UBS Quant

Nonetheless, this is a simple and intuitive approach which can easily be modelled with conventional tools like Excel. To review the very early literature in this space, refer to Chow and Lin (1971) and Friedman (1962).

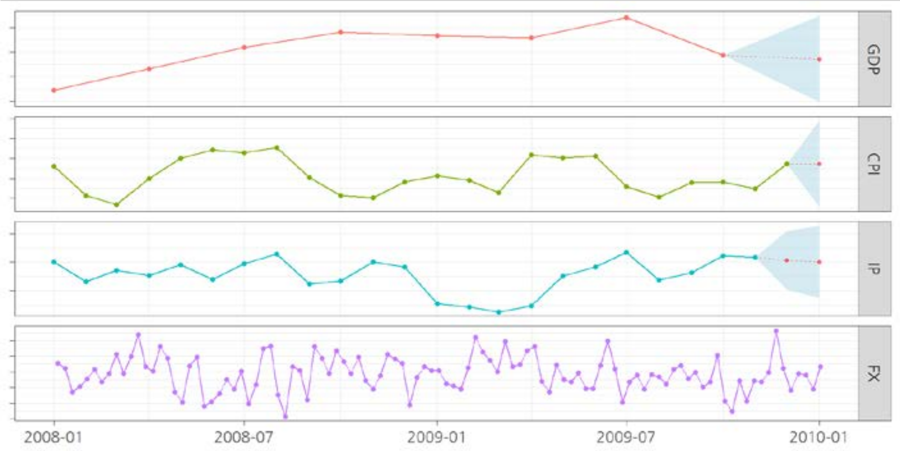
Bridge equations

Bridge equations are a long-standing solution, still actively in use today

These are one of the earliest techniques for handling mixed frequency regressions, and remain popular for short-term forecasting at many central banks today, owing to their simplicity and transparency. Bridge equations simply work by:

1. Forecasting the high frequency predictors out to the low frequency time horizon, typically using a simple univariate model, thereby tidying up the ragged edge of the high frequency data
2. Aggregating these high frequency forecasts to the low frequency
3. Calculating an ordinary linear regression of the low frequency variable of interest against lags of itself and lags of these aggregates

Figure 2: Forecasting and aggregating the ragged edge with bridge models



Source: UBS Quant

Bridge equations are a modest innovation to aggregating; though they are not without their shortcomings

This procedure is just a modest innovation on temporal aggregation; it introduces univariate forecasts into the high frequency predictors, an autoregressive term, and distributed lags of the high frequency components. As for temporal aggregation, it only requires Excel to produce forecasts, so the technique is widely accessible. For recommended further reading, refer to Baffigi et al. (2004).

While this remains a popular technique in use today (rightly so), there are several weaknesses with this approach[1]:

- The univariate high frequency models are typically of weak predictive strength and might be mis-specified
- There is not necessarily any reason *a priori* to assume the lag structure should be equal-weighted as is implicit in the bridge model[2]
- With a sufficiently high lag order, the bridge model may suffer from parameter proliferation, i.e. too many parameters (and usually too little data)

[1] Refer to Schumacher (2014) for an extensive analysis
[2] Indeed Andreou et al (2010) find that the regression coefficients under such a scheme may yield asymptotically inefficient at best, and potentially inconsistent parameter estimates

- The bridge model cannot make use of intra-low frequency period information, i.e. the model cannot be re-estimated until information for the full-period is available

The MIDAS model was introduced to address some of these shortcomings.

Mixed Data Sampling (MIDAS)

MIDAS is a fairly recent development for computing nowcasts that has seemingly gained popularity. Introduced by Ghysels (2004), the basic idea is to introduce a smooth functional form that describes the high frequency lag weights with just a handful of parameters[3].

It is desirable to introduce a parsimonious form to these lags because, all else being equal, fewer parameters are preferable to more parameters: there is less chance of overfitting and misspecification, it is computationally more efficient, and arguably more fitting with our intuition in time series; we do not expect that lag coefficients vary much from one day to another.

"With four parameters I can fit an elephant, and with five I can make him wiggle his trunk"

- John von Neumann

The cost of introducing a parametrized functional form (as opposed to explicitly aggregation or estimating the parameters jointly), is that the regression becomes non-linear and thus no longer has a closed form, rather it requires an optimiser to calculate. This places the technique out of computing reach within Excel; however this tool is available in R, Matlab and EViews, at least.

Notable other approaches

We omit some notable alternative techniques for brevity—this is not an exhaustive list of nowcasting tools at an investors' disposal. Most notably missing are dynamic factor models and mixed-frequency VAR models; the former of which has arguably seen the widest application to GDP nowcasting problems to date.

We omit some useful alternatives for brevity; these will be explored in subsequent reports

However these alternative techniques are also considerably more computationally intensive than MIDAS. If you are constructing a mixed frequency regression with strong prior information and perhaps relatively little data to work with, then a state space model may be appropriate. If you are constructing millions of mixed frequency regressions over fund holdings as used in our report on behavioural finance[4], then MIDAS makes an excellent alternative.

MIDAS is considerably more computationally efficient than these alternatives

Another task not addressed here is that of variable selection, i.e. which parameters should be included in the mixed frequency regression and how many should there be. A popular approach first introduced by Giannone, Reichlin and Small (2008) combines the principal components of a large dataset with the Kalman filter, obviating this concern. Other approaches attempt to apply stronger economic theory with fewer predictors; recent innovations consider penalised regressions and model pooling.

Another task not addressed here is that of variable selection

However note that MIDAS regressions suffer from the "curse of dimensionality"; incorporating a large number of regressors to the model is unlikely to yield useful results; it is advisable to apply regressors sparingly and judiciously. Extensions to the traditional MIDAS technique, named Factor-MIDAS, were developed to address this – refer to Marcellino and Schumacher (2008).

MIDAS regressions suffer from the curse of dimensionality

[3] For any readers already familiar with the concept, this is just an extension to the traditional distributed lag model; here obviously applied to timeseries captured at mixed frequencies.
[4] See "Irrational Asset Management", Oct 2016, https://neo.ubs.com/shared/d1BupxpEFrgFZ

Getting started

Due to data redistribution limitations, we use two datasets that are included with the *midasr* package; annual US real GDP and monthly US unemployment series dating back to 1948. Our objective here is nowcasting GDP using unemployment; for this we first need to set up the lag structures in much the same fashion as you might for temporal aggregation or a bridge model.

Please run the examples through in order – they are not standalone

`mls(x, k, m)` is the workhorse function that creates this lag structure for the high frequency variable, `x`

- `k` is the number of high frequency distributed lag components to include
- `m` is the ratio of the high frequency (HF) to low frequency (LF) sampling, i.e. here it is 12/1=12

Figure 3: Creating the lag structures

```
require(midasr)
require(ggplot2)
require(data.table)
data('USrealgdp') # US GDP (annual)
data('USunempr')  # US unemployment rate (monthly)

y <- diff(log(USrealgdp))
x <- window(diff(USunempr), start=1949)

# 12 months of HF data for every annual data point (note 0 refers to no lag)
mls(x, 0:11, 12)

# there can be many more lags than "m", e.g. 2 years of HF data for every LF data point
mls(x, 0:23, 12)

# or say only we only care about the 4Q data
mls(x, 0:2, 12)

# if the LF response is not trend stationary, an autoregressive component can be modelled
mls(y, 1, 1)
```

Source: UBS Quant

Choosing a lag function

There are seemingly too many choices to make when it comes to lag functions; many options with no objectively "best" candidate. Figure 4 shows the functions available within the *midasr* package alone; some of which are referenced nowhere in the literature (perhaps a solution looking for a problem). Note each weighting method is accompanied with its explicit gradient for the non-linear optimiser.

There are seemingly too many choices of lag function; some of which have not yet been applied in the literature

Figure 4: Lag functions available within midasr

Function	Name	References
`almonp`	Almon polynomial	Almon (1965)
`nealmon`	Normalised exponential Almon lag	Ghysels, Santa-Clara, Valkanov (2005)
`harstep`	Heterogeneous autoregressive model of realised vol.	Corsi (2009)
`polystep`	Step function specification	Ghysels, Sinko, and Valkanov (2006)
`nbeta`	Normalized beta probability density	Ghysels, Sinko, and Valkanov (2006)
`genexp`	Generalised exponential	Kvedaras, Zemlys (2012)
`gompertzp`	Gompertz probability density	No references found
`lcauchyp`	Normalized log-Cauchy probability density	No references found
`nakagamip`	Normalized Nakagami probability density	No references found

Source: UBS Quant

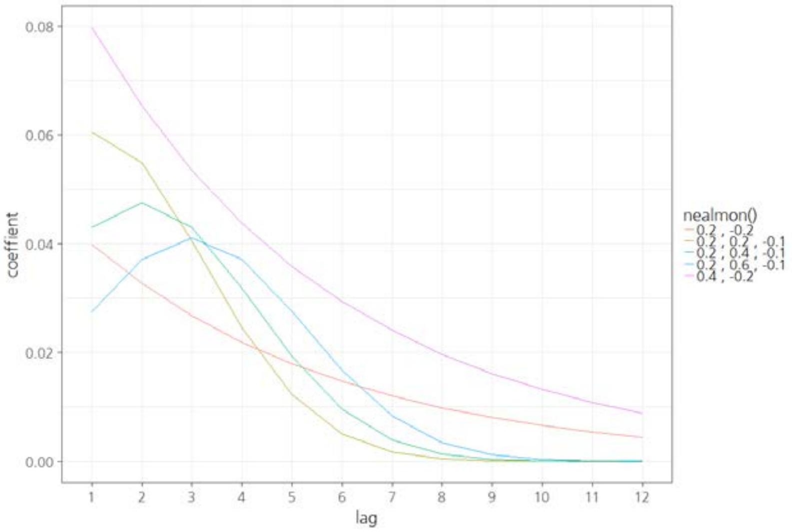
However, the econometric literature supporting the normalised exponential Almon lag is arguably the most extensive, and the lag function itself is sufficiently flexible to capture any conceivable lag structure we might encounter. Figure 5 graphs the form of these curves for various parameters.

Figure 5: Illustrative parameters for the normalised exponential Almon lag

```
params <- list(c(0.2, -0.2), c(0.4, -0.2), c(0.2, 0.2, -0.1), c(0.2, 0.4, -0.1), c(0.2, 0.6, -0.1))

coefs <- rbindlist(lapply(params, function(k) {
  data.table(arg=paste(k, collapse=' , '), lag=seq(12), coef=nealmon(k, d=12)) }))

require(ggplot2)
ggplot(coefs) + geom_line(aes(factor(lag), coef, group=arg, color=arg)) +
  scale_color_discrete(name='nealmon()') + ylab('coeffient') + xlab('lag')
```



Source: UBS Quant

Running the regression

Otherwise the regression itself is straightforward to execute; the familiar formula interface and methods are supported. Note the lag function is specified in the `mls` call, and the initial values for the parameters must be provided to the optimiser.

Figure 6: Running the regression

```
# build the model, using an autoregressive term and a 12m lag structure
m <- midas_r(y ~ mls(y, 1, 1) + mls(x, 0:11, 12, nealmon), start=list(x=rep(0, 3)))

# always check the residuals! these don't look good; there appears to be a downward trend
plot(resid(m))

# we can incorporate a deterministic trend component too. these residuals look ok
trend <- seq_along(y)
m <- midas_r(y ~ trend + mls(y, 1, 1) + mls(x, 0:11, 12, nealmon), start=list(x=rep(0, 3)))

# you can obtain test statistics of the coefficients in the usual manner
summary(m)

# Formula y ~ trend + mls(y, 1, 1) + mls(x, 0:11, 12, nealmon)
# Parameters:
#               Estimate Std. Error t value Pr(>|t|)
# (Intercept)  3.977e-02  3.277e-03  12.136  < 2e-16 ***
# trend       -2.739e-04  6.794e-05  -4.032 0.000169 ***
# y            4.146e-02  6.217e-02   0.667 0.507662
# x1          -2.059e-01  1.262e-02 -16.317  < 2e-16 ***
# x2           9.073e-01  4.046e-01   2.243 0.028898 *
# x3          -4.870e-02  2.459e-02  -1.981 0.052554 .
```

Source: UBS Quant

Unfortunately there is no systematic way to identify ideal starting points for all lag methods. Choosing extreme values (e.g. initialising them all to 100) will result in an optimisation error; choosing less extreme but still unrealistic figures (e.g. setting them to 1), will result in meaningless results and the robust (sandwich) estimator failing. However with the exponential Almon lag, initial values of 0 are seemingly quite common and yield good results.

Initialising the exponential Almon lag parameters to 0 yields good results

Checking the coefficients

Once the regression has been performed, there are several diagnostics available for testing the adequacy of the lag function. The summary shown in Figure 6 above yields the fitted parameters for the lag function; subsequently evaluating the lag function using these parameters then comparing the results to the unrestricted regression (i.e. without these smoothness constraints imposed), gives a graphical representation of how closely the fit matches the data.

Once the regression has been performed, there are tools to test its fit

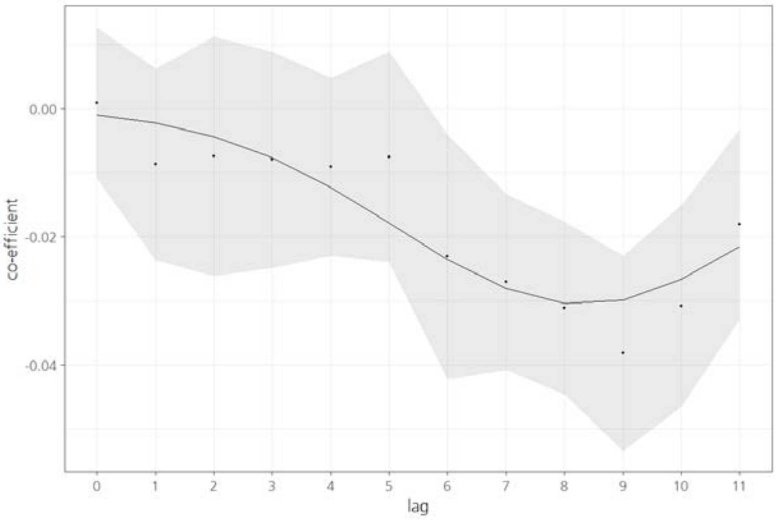
Figure 7: Plotting the regression coefficients

```
# you can access the fitted coefficients through coef() but this is a clumsy method
# note these x1/2/3 correspond to the parametrised function form
nealmon(tail(coef(m), 3)

# there is an in-built function for plotting the lag coefficients about their confidence interval
plot_midas_coef(m, term_name='x')

# or you can extract them manually, e.g. for ggplot
ti <- m$term_info[['x']]$midas_coef_index
mcoef <- coef(m, midas = TRUE)[ti]
ucoef <- coef(m$unrestricted)[ti]
sdval <- sqrt(diag(sandwich(m$unrestricted)))[ti]
pd <- data.frame(lag=seq(0, 11), restricted=mcoef, unrestricted=ucoef,
              lower=ucoef - 1.96 * sdval, upper=ucoef + 1.96 * sdval)

ggplot(pd) +
  geom_ribbon(aes(lag, ymin=lower, ymax=upper), alpha=0.1) +
  geom_line(aes(lag, restricted)) + ylab('co-efficient') +
  geom_point(aes(lag, unrestricted)) +
  scale_x_continuous(breaks=seq(12)-1, minor_breaks=NULL)
```




```
# there is also a statistical test on the appropriateness of the lag function
# i.e. under the H0 that the chosen lag functional constraint fits the DGP
# refer to Kvedaras and Zemlys (2012) for the implementation details
hAh_test(m)
hAhr_test(m) # uses the robust estimator
```

Source: UBS Quant

Model selection

Clearly there are several model parameters at the user's discretion using this technique; with few opportunities to incorporate meaningful prior information into the model, there are methods that assist in model selection (overfitting concerns notwithstanding).

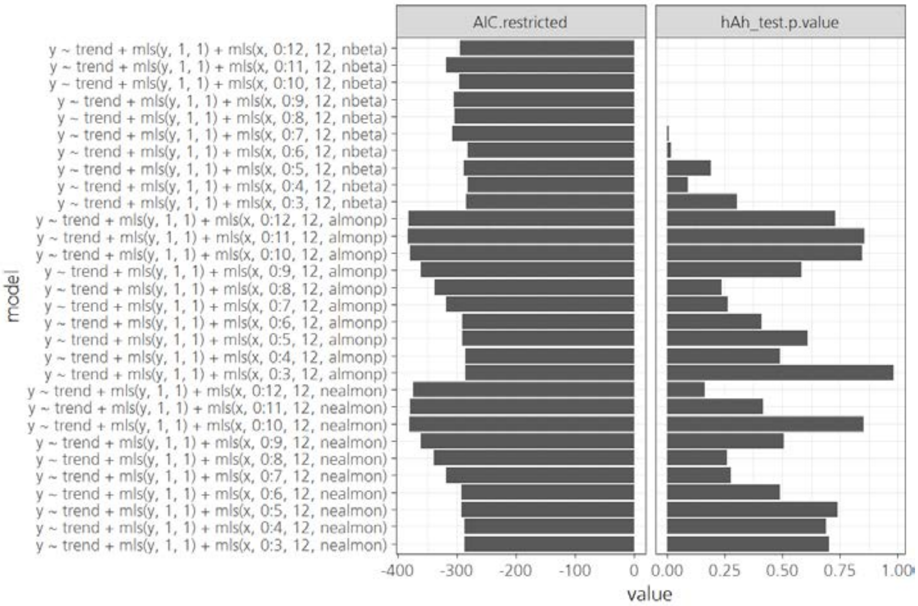
It is straightforward to generate several permutations of parameters using the function `expand_weights_lags`, and then subsequently evaluate them on the basis of their AIC/BIC using the `midas_r_ic_table` function, as in Figure 8. Also shown is the hypothesis test above, whose null corresponds to an appropriate lag specification.

Figure 8: Testing several models

```r
# it's simple to build a table of model permutations to evaluate
params <- expand_weights_lags(weights = c('nealmon', 'almonp', 'nbeta'),
        m=1, from=0, to=c(3, 12),
        start=list(nealmon = rep(1, 2), almonp=rep(1, 3), nbeta=c(1, 1, 0)))

# generate the models and check their information criteria
models <- midas_r_ic_table(y ~ trend + mls(y, 1, 1) + mls(x, 0, 12), table=list(x=params))
results <- data.table(models$table)[, model:=factor(model, levels=model)]

# our original choice of model seems appropriate:
# the AIC is roughly minimised and we cannot reject the H0 of an appropriate lag specification
ggplot(melt(results[, c('model', 'AIC.restricted', 'hAh_test.p.value')], id.vars=c('model'))) +
  geom_bar(aes(model, value), stat='identity') +
  facet_wrap(~variable, scales='free_x', nrow=1) + coord_flip()
```



Source: UBS Quant

Nowcasting

Our objective is to conduct nowcasts; essentially exploiting mismatches in sampling frequencies and reporting delays of the predictors. Fortunately the package has the functionality to easily compute these forecasts, including the necessary timeseries cross-validation. `average_forecast` performs a rolling or expanding window model re-estimation procedure, given the specified test and training data.

Our ultimate objective is to actually conduct forecasts exploiting sampling frequency and reporting lag mismatches

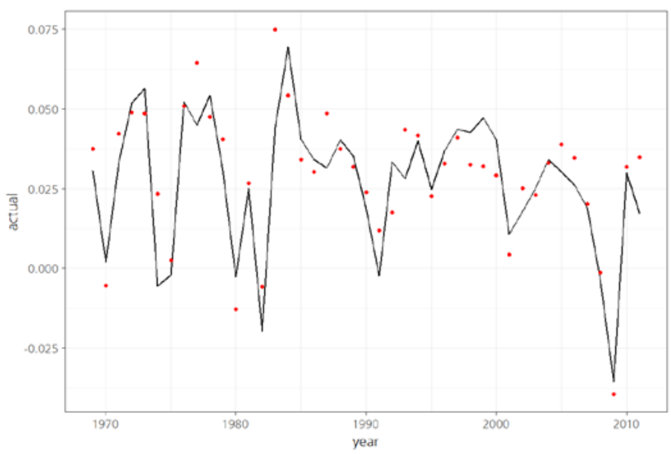
It returns detailed information including the traditional mean square error (MSE), the mean absolute percentage error (MAPE), and the preferred mean absolute scaled error (MASE) statistics for the in-sample and out-of-sample data.

Figure 9: Performing a forecast

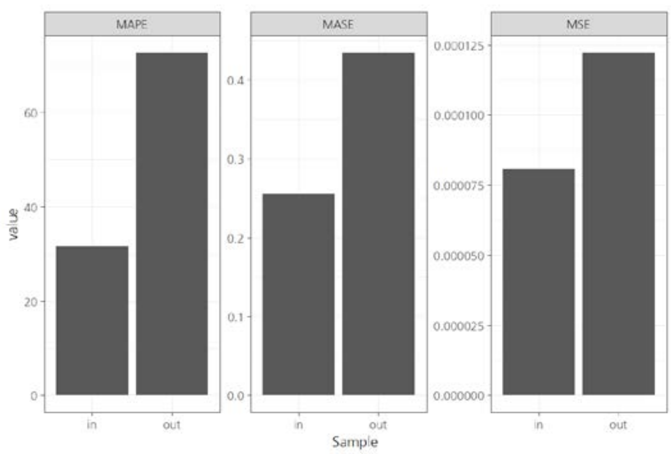
```
# specify the minimum training set length (in terms of the LF frequency)
insample <- seq(20) # years
outsample <- seq_along(y)[-insample]

# let's keep the model "m", that we built earlier
# type='recursive' builds an expanding window beyond the in-sample training data
fcst <- average_forecast(list(m), data=list(y=y, x=x, trend=trend),
  insample=insample, outsample=outsample, type='recursive', show_progress=T)

# plot the nowcasts of diff(log(GDP)) shown in red dots against the actual figure
tsres <- data.table(year=time(y)[outsample], actual=y[outsample], nowcast=drop(fcst$forecast))
ggplot(tsres) + geom_line(aes(year, actual), size=1) + geom_point(aes(year, nowcast), color='red')
```




```
# we can extract detailed performance statistics like this
perf <- melt(data.table(fcst$accuracy$individual)[, Model:=factor(Model, levels=Model)], id.vars='Model')
perf[, c('IC', 'Sample'):=tstrsplit(variable, '.', fixed=T, keep=c(1,2))]
ggplot(perf, aes(Sample, value)) + geom_bar(stat='identity') + facet_wrap(~IC, scales='free_y')
```



Source: UBS Quant

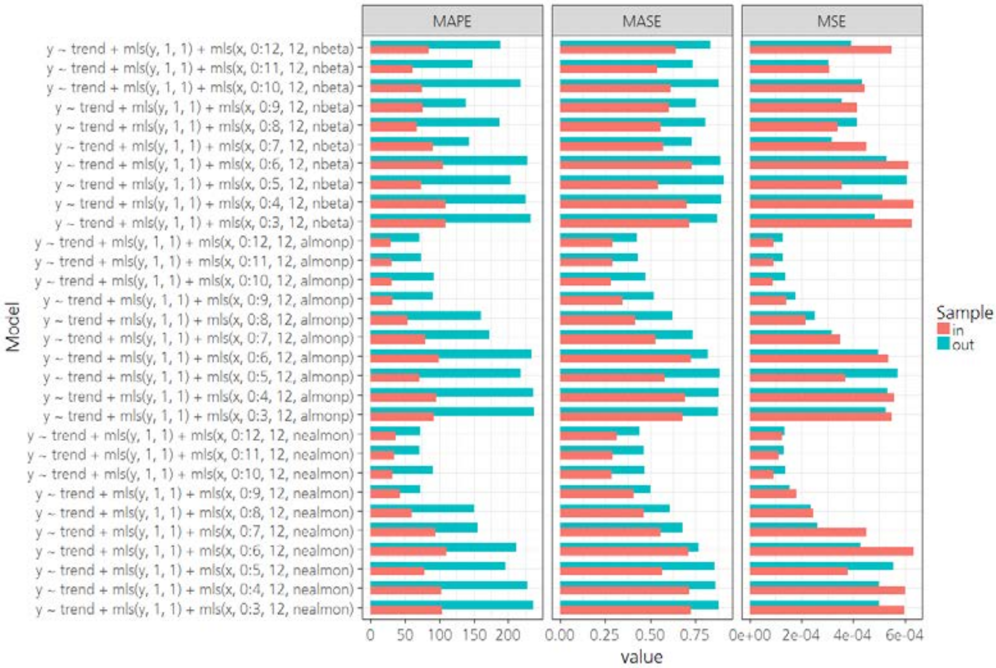
The accuracy of any forecasts could be considered as relative to baseline models; a univariate timeseries model like AR(1), or even simple mixed-frequency models like the temporal aggregation/bridge models as discussed. It is also possible to consider the out of sample accuracy for each of the models shown in Figure 8; the model selected earlier again appears to be near-optimal amongst these candidates.

Figure 10: Testing in/out of sample performance for several model candidates

```
# we can also evaluate the errors of the permutations tested above
fcst <- average_forecast(models$candlist, data=list(y=y, x=x, trend=trend),
  insample=insample, outsample=outsample, type='recursive', show_progress=T)

perf <- melt(data.table(fcst$accuracy$individual)[, Model:=factor(Model, levels=Model)], id.vars='Model')
perf[, c('IC', 'Sample'):=tstrsplit(variable, '.', fixed=T, keep=c(1,2))]

# plot the in/out of sample errors for each model
ggplot(perf, aes(Model, value, fill=Sample)) +
  geom_bar(stat='identity', position=position_dodge(width = 0.5)) +
  facet_wrap(~IC, scales='free_x', nrow=1) + coord_flip()
```



Source: UBS Quant

Appendix

We provide a brief description of this technique below. A traditional autoregressive distributed lag model for forecasting with an autoregressive lag order of p and a regressor lag order q, using two series sampled equal frequency, can be expressed:

$$y_{t+1}^{LF} = \mu + \sum_{j=0}^{p} \varphi_{j+1}\, y_{t-j}^{LF} + \sum_{j=0}^{q} \beta_{j+1}\, x_{t-j}^{LF} + \varepsilon_{t+1}$$

The MIDAS approach is an extension to this, applying distributed lag polynomials to a mixed frequency regression. We could simply regress lags of high frequency data onto the low frequency data, but this would require estimating far too many parameters; a more parsimonious representation is just to hyperparametrise the lag function ω between the mixed frequency series, where N is the number of intra-period lags relative to the low frequency variable.

$$y_{t+1}^{LF} = \mu + \sum_{j=0}^{p} \varphi_{j+1}\, y_{t-j}^{LF} + \beta \sum_{j=0}^{q} \sum_{i=0}^{N-1} \omega_{i+j\cdot N}(\boldsymbol{\theta})\, x_{N-i,t-j}^{HF} + \varepsilon_{t+1}$$

With the normalised exponential Almon lag polynomial with s parameters

$$\omega_k(\boldsymbol{\theta}) = \frac{\varpi_k(\boldsymbol{\theta})}{\sum_k \varpi_k(\boldsymbol{\theta})}, \qquad \varpi_k(\boldsymbol{\theta}) = \exp(\sum_{i=1}^{s} \theta_i k^i)$$

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Sell	FSR is > 6% below the MRA.	16%	11%
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 30 September 2017.
1:Percentage of companies under coverage globally within the 12-month rating category.
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