ETC3550/ETC5550 Applied forecasting

Week 10: ARIMA models

Seasonal ARIMA models

ARIMA	(p, d, q)	$(P, D, Q)_m$
	↑	↑
	Non-seasonal part of the model	Seasonal part of of the model

where m = number of observations per year.

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$\begin{pmatrix}\text{Non-seasonal}\\\text{AR(1)}\end{pmatrix}$ $\begin{pmatrix}\text{Seasonal}\\\text{AR(1)}\end{pmatrix}$ $\begin{pmatrix}\text{Non-seasonal}\\\text{difference}\end{pmatrix}$ $\begin{pmatrix}\text{Seasonal}\\\text{difference}\end{pmatrix}$ $\begin{pmatrix}\text{Non-seasonal}\\\text{MA(1)}\end{pmatrix}$ $\begin{pmatrix}\text{Seasonal}\\\text{MA(1)}\end{pmatrix}$

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All the factors can be multiplied out and the general model written as follows:

$$
\begin{aligned}
y_t = {} & (1 + \phi_1)y_{t-1} - \phi_1 y_{t-2} + (1 + \Phi_1)y_{t-4} \\
& - (1 + \phi_1 + \Phi_1 + \phi_1 \Phi_1)y_{t-5} + (\phi_1 + \phi_1 \Phi_1)y_{t-6} \\
& - \Phi_1 y_{t-8} + (\Phi_1 + \phi_1 \Phi_1)y_{t-9} - \phi_1 \Phi_1 y_{t-10} \\
& + \varepsilon_t + \theta_1 \varepsilon_{t-1} + \Theta_1 \varepsilon_{t-4} + \theta_1 \Theta_1 \varepsilon_{t-5}.
\end{aligned}
$$

Seasonal ARIMA models

The seasonal part of an AR or MA model will be seen in the seasonal lags of the PACF and ACF.

ARIMA$(0,0,0)(0,0,1)_{12}$ will show:
- a spike at lag 12 in the ACF but no other significant spikes.
- The PACF will show exponential decay in the seasonal lags; that is, at lags 12, 24, 36, ...

ARIMA$(0,0,0)(1,0,0)_{12}$ will show:
- exponential decay in the seasonal lags of the ACF
- a single significant spike at lag 12 in the PACF.

Point forecasts

1. Rearrange ARIMA equation so y_t is on LHS.
2. Rewrite equation by replacing t by $T + h$.
3. On RHS, replace future observations by their forecasts, future errors by zero, and past errors by corresponding residuals.

Start with $h = 1$. Repeat for $h = 2, 3, \ldots$.

Prediction intervals

95% prediction interval

$$\hat{y}_{T+h|T} \pm 1.96\sqrt{v_{T+h|T}}$$

where $v_{T+h|T}$ is estimated forecast variance.

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- $v_{T+1|T} = \hat{\sigma}^2$ for all ARIMA models regardless of parameters and orders.
- Multi-step prediction intervals for ARIMA(0,0,q):

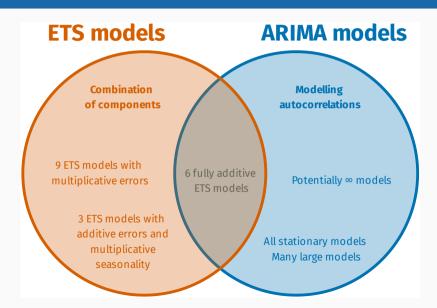$$y_t = \varepsilon_t + \sum_{i=1}^{q} \theta_i \varepsilon_{t-i}.$$

$$v_{T|T+h} = \hat{\sigma}^2 \left[1 + \sum_{i=1}^{h-1} \theta_i^2 \right], \qquad \text{for } h = 2, 3, \dots.$$

Prediction intervals

- Prediction intervals **increase in size with forecast horizon**.
- Prediction intervals can be difficult to calculate by hand
- Calculations assume residuals are **uncorrelated** and **normally distributed**.
- Prediction intervals tend to be too narrow.
    - the uncertainty in the parameter estimates has not been accounted for.
    - the ARIMA model assumes historical patterns will not change during the forecast period.
    - the ARIMA model assumes uncorrelated future errors

ARIMA vs ETS

- Myth that ARIMA models are more general than exponential smoothing.
- Linear exponential smoothing models all special cases of ARIMA models.
- Non-linear exponential smoothing models have no equivalent ARIMA counterparts.
- Many ARIMA models have no exponential smoothing counterparts.
- ETS models all non-stationary. Models with seasonality or non-damped trend (or both) have two unit roots; all other models have one unit root.

ARIMA vs ETS

Equivalences

ETS model	ARIMA model	Parameters
ETS(A,N,N)	ARIMA(0,1,1)	$\theta_1 = \alpha - 1$
ETS(A,A,N)	ARIMA(0,2,2)	$\theta_1 = \alpha + \beta - 2$
		$\theta_2 = 1 - \alpha$
ETS(A,A$_d$,N)	ARIMA(1,1,2)	$\phi_1 = \phi$
		$\theta_1 = \alpha + \phi\beta - 1 - \phi$
		$\theta_2 = (1 - \alpha)\phi$
ETS(A,N,A)	ARIMA(0,0,m)(0,1,0)$_m$	
ETS(A,A,A)	ARIMA(0,1,m + 1)(0,1,0)$_m$	
ETS(A,A$_d$,A)	ARIMA(1,0,m + 1)(0,1,0)$_m$	