Time Series

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Outline I

1. Testing the Noise Sequence
   - Testing i.i.d Sequence
   - Testing Normality

Testing the Noise Sequence I

- If there is no dependence among the residuals, then
  - we can regard them as observations of independent random variables,
  - and there is no further modeling to be done except to estimate their mean and variance.
- However, if there is significant dependence among the residuals, then
  - we need to look for a more complex model for the noise that accounts for the dependence.
  - as a result, the past observations of the noise sequence can assist in predicting future values.

Testing the Noise Sequence II

- Therefore, we examine some simple tests for checking the hypothesis that the *residuals are observed values of independent and identically distributed random variables.*

The sample autocorrelation function I

- For large n, the sample auto-correlations of an *i.i.d.* sequence $X_1, \ldots, X_n$ is defined as

$$\hat{\rho}(h) = \frac{\hat{\gamma}(h)}{\hat{\gamma}(0)} \text{ for } -n < h < n,$$

where $\hat{\gamma}(h) = n^{-1} \sum_{t=1}^{n-|h|} (x_{t+h} - \bar{x})(x_t - \bar{x})$ and $\bar{x} = n^{-1} \sum_{t=1}^{n} x_t$.

The sample autocorrelation function II

- The auto-correlations of an **i.i.d. sequence** $X_1, \ldots, X_n$, **with finite variance** are approximately *i.i.d.* with distribution $N(0, 1/n)$
- Hence, if $x_1, \ldots, x_n$ is a realization of such an *i.i.d.* sequence, about 95% of the sample auto-correlations should fall between the bounds $\pm 1.96/\sqrt{n}$.

The portmanteau test I

- Instead of checking to see whether each sample auto-correlation $\hat{\rho}(j)$ falls inside the bounds defined above, it is also possible to consider the single statistic

$$Q = n \sum_{j=1}^{h} \hat{\rho}^2(j).$$

- For an **i.i.d. sequence** $X_1, \ldots, X_n$, **with finite variance** Q is approximately distributed as the sum of squares of the independent $N(0,1)$ random variables, $\sqrt{n}\hat{\rho}(j), j = 1, \ldots, h$, i.e., as chi-squared with h degrees of freedom.

The portmanteau test II

- A large value of Q suggests that the sample autocorrelations of the data are too large for the data to be a sample from an *i.i.d.* sequence.
  - We therefore reject the *i.i.d.* hypothesis at level α if $Q > \chi^2_{1-\alpha}(h)$, where $\chi^2_{1-\alpha}(h)$ is the $1-\alpha$ quantile of the chi-squared distribution with h degrees of freedom.

Ljung Box test I

- A better and modified estimator

$$Q_{LB} = n(n+2)\sum_{j=1}^{h} \hat{\rho}^2(j)/(n-j).$$

- For an **i.i.d. sequence** $X_1, \ldots, X_n$, **with finite variance** Q is approximately distributed as a chi-squared with h degrees of freedom.

Ljung Box test II

- A large value of Q_{LB} suggests that the sample autocorrelations of the data are too large for the data to be a sample from an *i.i.d.* sequence.
    - We therefore reject the *i.i.d.* hypothesis at level α if $Q_{LB} > \chi^2_{1-\alpha}(h)$, where $\chi^2_{1-\alpha}(h)$ is the $1-\alpha$ quantile of the chi-squared distribution with h degrees of freedom.

The turning point test I

- If $x_1, \ldots, x_n$ is a sequence of observations, we say that there is a turning point at time $i, 1 < i < n$,
  - if $x_{i-1} < x_i$ and $x_i > x_{i+1}$ or if $x_{i-1} > x_i$ and $x_i < x_{i+1}$.
- If **T** is the number of turning points of an **i.i.d. sequence** of length n, then,
  - the probability that a point at time i is a turning point is $\frac{2}{3}$
  - $\mu_T = E[T] = 2(n-2)/3$
  - $\sigma_T^2 = Var[T] = (16n - 29)/90$

The turning point test II

- A large value of $T - \mu_T$ indicates that the series is fluctuating more rapidly than expected for an *i.i.d.* sequence.
- On the other hand, a value of $T - \mu_T$ much smaller than zero indicates a positive correlation between neighboring observations.

The turning point test III

- For an *i.i.d.* sequence with n large, it can be shown that T is approximately $N(\mu_T, \sigma_T^2)$.
- Therefore, we can carry out a test of the **i.i.d.** hypothesis and reject it at level α if $|T - \mu_T|/\sigma_T > z_{1-\alpha/2}$,
  - where $z_{1-\alpha/2}$ is the $1 - \alpha/2$ quantile of the standard normal distribution

The test for Normality. I

Q-Q Plot: Graphical check for normality

Steps:

- Given an *i.i.d.* sequence $\{x_1, x_2, \ldots, x_n\}$ turn it to a standardized form $\{z_1, z_2, \ldots, z_n\}$
- Sort the standardized sequence to $\{z_{(1)}, z_{(2)}, \ldots, z_{(n)}\}$

The test for Normality. II

- Corresponding to each $z_{(i)}$ calculate the associated quantile from standard normal $N_{q_{z_{(i)}}}$, such that,

$$P\left(Y \leq N_{q_{z_{(i)}}}\right) = \frac{i - 0.5}{n},$$

where $Y \sim N(0, 1)$.

  - Note: Empirical distribution of Z:
    $P(Z \leq z_{(i)}) = \frac{\text{Number of points less than equal } z_{(i)}}{\text{Total Points}} = \frac{i}{n}$
- Plot the pair points $(N_{q_{z_{(i)}}}, Z_{(i)})$ for $i = 1, \ldots, n$
- If the sequence $\{x_1, x_2, \ldots, x_n\}$ is coming from normal, the plot described above will be straight line passing through origin with slop 1.

The test for Normality. III

Shapiro R^2 test (Shapiro-Francia test)

- Test Statistics, under normality assumption:

$$R^2 = \frac{\left[\sum_{i=1}^{n} N_{qZ_{(i)}} Z_{(i)}\right]^2}{\sum_{i=1}^{n} \left[N_{qZ_{(i)}}\right]^2 \sum_{i=1}^{n} \left[Z_{(i)}\right]^2}$$

- The assumption of normality is rejected if the squared correlation R^2 is sufficiently small
- p values can be found from standard tables
- Decision on Acceptance/Rejection of normality can be made by seeing the p value