

程序代写代做 CS编程辅导

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F Econometrics
Slides-05: Time Series Analysis using ARMA models
Part 2



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Dr. Rachida Ouyse
Assignment Project Exam Help
School of Economics¹

Email: tutorcs@163.com

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Time Series Models (Main Statistical Aspects)

- MA process
- AR process
 - Wold Decomposition
 - AF and PACF patterns
 - Impulse response function

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Defining Moving Average Process $MA(q)$

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■ Moving average model

- In Wold decomposition as $i \rightarrow \infty$. A simple approximation to the GLP is to restricting



$$\theta_i = 0 \text{ for all } i > q.$$

- The result is $MA(q)$ model:

$$y_t = \mu + \epsilon_t + \theta_1 \epsilon_{t-1} + \dots + \theta_q \epsilon_{t-q}, \quad \epsilon_t \sim \text{i.i.d } WN(0, \sigma^2),$$

where y_t is the "average" of the current shock and its q recent lags. The shock ϵ_t and its lags are unobservable.

- Use lag operator $L: Lz_t = z_{t-1}$ to write $MA(q)$:

$$y_t = \mu + \Theta(L)\epsilon_t,$$

where

$$\Theta(L) = 1 + \theta_1 L + \theta_2 L^2 + \dots + \theta_q L^q.$$

MA(1) model

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■ MA(1) model

- MA(1) model (as a data generating process)

$$y_t = \mu + \epsilon_t + \theta_1 \epsilon_{t-1}, \epsilon_t \sim \text{i.i.d } WN(0, \sigma^2),$$

- MA(1):

where $\Theta(L) = 1 + \theta_1 L$.

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MA(1) model: Unconditional moments

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■ MA(1) model: Characteristic

- It is always stationary

$$E(y_t) = \mu, \text{Var}(y_t) = (1 + \theta_1^2)\sigma^2,$$

$$\gamma_j = \text{Cov}(y_t, y_{t-j}) = \begin{cases} \theta_1 \sigma^2, & j = 1 \\ 0, & j > 1 \end{cases}$$

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$$\rho_j = \frac{\gamma_j}{\gamma_0} = \begin{cases} \theta_1 / (1 + \theta_1^2), & j = 1 \\ 0, & j > 1 \end{cases}$$

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- If the estimated $\hat{\rho}_j$ has a cutoff at $j = 1$, the time series may be fitted in an MA(1) model.

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MA(1) model: Conditional moments

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■ MA(1) model: Conditional moments

- Conditional on $\Omega_t = \{\epsilon_t, \epsilon_{t-1}, \dots; y_t, y_{t-1}, \dots\}$

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$$E(y_{t+h}|\Omega_t) = \begin{cases} \mu + \theta_1 \epsilon_t, & h = 1 \\ \mu, & h > 1 \end{cases}$$

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$$Var(y_{t+h}|\Omega_t) = \begin{cases} \sigma^2, & h = 1 \\ (1 + \theta_1^2)\sigma^2, & h > 1 \end{cases}$$

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- Conditional variance \leq unconditional variance (why?)

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MA(1) model: Dynamic Behavior

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■ MA(1) model: Impulse response function

- the effect on y_{t+h} of a one-std-deviation increase in ϵ_t :

$$\sigma \frac{\delta y_{t+h}}{\delta \epsilon_t} = \begin{cases} \sigma \theta_1, & h=1 \\ 0, & h>1 \end{cases}.$$

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MA(1) model: Invertibility

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■ MA(1) model: Invertibility

- Can we back out ϵ_t from:

$$\rho_j = \frac{\gamma_j}{\gamma_0} = \begin{cases} \theta_1/(1 + \theta_1^2), & j = 1 \\ 0, & j \geq 2 \end{cases}$$

Can we get to know $\{\epsilon_t, \epsilon_{t-1}, \dots\}$ based on $\{y_t, y_{t-1}, \dots\}$?

- Yes if MA is invertible
- The MA(q) process $y_t = \mu + \Theta(L)\epsilon_t$ is invertible if the roots of $\Theta(z) = 0$ are all outside the unit circle.
- For MA(1), the root of $1 + \theta_1 z = 0$ is $z = -1/\theta_1$. Hence, MA(1) is invertible when $|-1/\theta_1| > 1$ or $|\theta_1| < 1$.
- Invertible in the sense that $\Theta(L)^{-1}$ exists properly.

MA(1) model: Invertibility

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■ MA(1) model: Invertibility

- When MA is invertible, the shock may be recovered from the observable:
 $\epsilon_t = \Theta(L)^{-1}(y_t - \mu)$, when invertible,



$$\Theta(L)^{-1} = (1 + \theta_1 L)^{-1} = 1 + (-\theta_1)L + (-\theta_1)^2 L^2 + \dots, \quad (1)$$

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$$\epsilon_t = y_t - \mu + \sum_{i=1}^{\infty} (-\theta_1)^i (y_{t-i} - \mu) \quad (2)$$

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$$= y_t + \sum_{i=1}^{\infty} (-\theta_1)^i y_{t-i} - \mu / (1 + \theta_1). \quad (3)$$

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Hint. Use expansion $\frac{1}{1-x} = 1 + x + x^2 + \dots$

- Parameters can be estimated by minimizing $\sum_{t=1}^T \epsilon_t^2$
- The alternative expression: $y_t - \mu / (1 + \theta_1) - \sum_{i=1}^{\infty} (-\theta_1)^i y_{t-i} + \epsilon_t$ indicates that the PAC function of invertible MA(1) has no cutoffs and decays exponentially.

MA(1) model: Example

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MA(1): simulated and fitted

eg. time series plot simulated MA(1)

$$\rho_1 = \theta_1 / (1 + \theta_1^2)$$



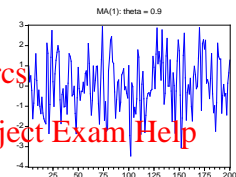
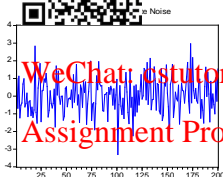
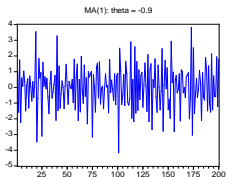
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eg. NYSE comp return

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.035311	0.02457	1.43729	0.1508
MA(1)	0.075177	0.02277	3.3031	0.0009

Correlation of AC					
Sample: 1 1991					
Included observations: 1938					
Autocorrelation	Partial Correlation	AC	PAC	Q-Stat	Prob.
1	0.000	0.000	0.0448	0.0039	
2	-0.006	-0.003	0.1196	0.005	
3	-0.021	-0.008	0.1490	0.0022	
4	-0.011	-0.001	0.1952	0.000	
5	-0.002	-0.000	0.2020	0.001	
6	-0.014	-0.000	0.2024	0.002	
7	-0.033	-0.007	0.2181	0.0007	
8	-0.011	-0.002	0.2190	0.003	
9	-0.023	-0.000	0.2181	0.003	
10	-0.028	-0.021	0.2173	0.003	
11	-0.043	-0.044	0.2170	0.001	
12	-0.054	-0.061	0.2181	0.0009	
13	-0.010	-0.004	0.2181	0.001	
14	-0.013	-0.000	0.2181	0.001	
15	-0.002	-0.000	0.2181	0.001	
16	-0.007	-0.001	0.2181	0.001	
17	-0.014	-0.001	0.2181	0.002	
18	-0.007	-0.001	0.2181	0.003	
19	-0.002	-0.000	0.2181	0.004	
20	-0.000	-0.000	0.2181	0.005	

MA(q) model: Dynamic Behaviour

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■ Dynamic Behaviour of a Moving Average Process $MA(q)$

An MA process is simply a combination of white noise error terms ϵ_t . These error terms can be thought of as **impulses** or **innovations** or **shocks** while the MA model describes the **dynamic impact** of these shocks on the series y_t .

The **impulse response function**, i.e. the dynamic impact of an impulse ϵ_t on y_t, y_{t+1}, \dots is given by

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$$\delta y_t / \delta \epsilon_t = 1$$

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$$\delta y_{t+q} / \delta \epsilon_t = \theta_q$$

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$$\delta y_{t+q+k} / \delta \epsilon_t = 0, \text{ for } k > 0$$

MA(q) model: Properties

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■ General Properties of Average Process $MA(q)$



- ▶ $E(y_t) = \mu$
- ▶ $\gamma_0 = (1 + \theta_1^2 + \theta_2^2 + \dots + \theta_q^2)\sigma^2$
- ▶ The ACF:

$$\begin{aligned}\gamma_k &= (\theta_k + \theta_{k-1}\theta_1 + \theta_{k-2}\theta_2 + \dots + \theta_q\theta_{q-k})\sigma^2, \text{ for } k = 1, \dots, q. \\ \gamma_k &= 0, \text{ for } k > q.\end{aligned}$$

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- ▶ The PACF? $p_k \neq 0 \forall k$ dies out slowly.

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■ Stationarity conditions for an MA process:

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- ▶ γ_0 is finite
- ▶ γ_k is finite

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⇒ a finite order MA process will always be stationary.

MA(q) Conclusions

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- ▶ As the **ACF cuts off** at q lags, the order of an MA process can be determined from inspection of the sample ACF.
- ▶ It can be shown (see below) that the **PACF dies out slowly**.
- ▶ A finite order MA process is **stationary by construction**, as it is a weighted sum of a fixed number of white noise processes, i.e. the mean, variance and autocovariances don't depend on time!

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Autoregressive Process: Definition

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Defining an Autoregressive Process

Let ε_t be a white noise process:


$$\begin{aligned} y_t &= \alpha_0 + \alpha_1 y_{t-1} + \alpha_2 y_{t-2} + \dots + \alpha_p y_{t-p} + \varepsilon_t \\ &= \alpha_0 + \sum_{i=1}^p \alpha_i y_{t-i} + \varepsilon_t \end{aligned} \quad (12)$$

is an **autoregressive process** of order p , denoted $AR(p)$.

→ y_t depends on its own lagged values and on the current value of a white noise disturbance term.

The model can conveniently be rewritten in so-called **lag operator notation** as

$$\begin{aligned} y_t &= \alpha_0 + \sum_{i=1}^p \alpha_i y_{t-i} + \varepsilon_t \quad \text{with } L^i y_t = y_{t-i} \\ \alpha(L) y_t &= \alpha_0 + \varepsilon_t \end{aligned} \quad (13)$$

where $\alpha(L) = 1 - \alpha_1 L - \alpha_2 L^2 - \dots - \alpha_p L^p$ is a lag polynomial of order p

AR Process: Impulse response function

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In an AR process, the value for y_t is a linear combination of past values plus a white noise ε_t . Again, these error terms can be seen as **impulse functions** or **shocks** while the AR model describes the **dynamic impact** of these shocks on the series y_t .

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In order to trace out the dynamic impact of an impulse ε_t on y_t, y_{t+1}, \dots , it is very convenient to first 'solve' the AR model in terms of the ε sequence. For notational convenience, first consider an AR(1) process

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$$y_t = \alpha_0 + \alpha_1 y_{t-1} + \varepsilon_t$$

where ε_t is a white noise process.

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AR Process: Impulse response function

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The easiest way to express y_t in terms of the ε sequence is to use **backward substitution**. This involves substituting

$$y_{t-1} = \alpha_0 + \alpha_1 y_{t-2} + \varepsilon_{t-1}$$

in the equation for y_t to obtain

$$\begin{aligned} y_t &= \alpha_0 + \alpha_1 (\alpha_0 + \alpha_1 y_{t-2} + \varepsilon_{t-1}) + \varepsilon_t \\ &= (1 + \alpha_1) \alpha_0 + \alpha_1^2 y_{t-2} + \alpha_1 \varepsilon_{t-1} + \varepsilon_t \end{aligned}$$

Next substitute

$$y_{t-2} = \alpha_0 + \alpha_1 y_{t-3} + \varepsilon_{t-2}$$

in the equation for y_t to obtain

$$y_t = (1 + \alpha_1 + \alpha_1^2) \alpha_0 + \alpha_1^3 y_{t-3} + \alpha_1^2 \varepsilon_{t-2} + \alpha_1 \varepsilon_{t-1} + \varepsilon_t$$

AR Process: Impulse response function

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After repeating this $t - 1$ times

$$\begin{aligned} y_t &= (1 + \alpha_1 + \dots + \alpha_1^{t-1})y_0 - \alpha_1^{t-1}\varepsilon_1 + \dots + \alpha_1\varepsilon_{t-1} + \varepsilon_t \\ &= \alpha_0 \sum_{i=0}^{t-1} \alpha_1^i + \alpha_1^t y_0 + \sum_{i=0}^{t-1} \alpha_1^i \varepsilon_{t-i} \end{aligned} \quad (14)$$

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where y_0 is the initial condition or the value for y in period 0.

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The **impulse response function** can now easily be obtained

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$$dy_t/d\varepsilon_t = \alpha_1^0 = 1$$

$$dy_{t+1}/d\varepsilon_t = \alpha_1^1$$

$$dy_{t+2}/d\varepsilon_t = \alpha_1^2$$

$$dy_{t+3}/d\varepsilon_t = \alpha_1^3$$

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AR Process: Convergence

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Note that whether an AR(1) process is mean-reverting after being hit by a shock depends on the value for α_1 . Two cases can be distinguished:

- ▶ The **convergence case** $|\alpha_1| < 1$
A shock affects all future observations but with a decreasing effect, i.e. the AR(1) process is mean-reverting
- ▶ The **non-convergence case** $|\alpha_1| \geq 1$
A shock affects all future observations but with an equal impact ($\alpha_1 = 1$) or with an increasing impact ($\alpha_1 > 1$), i.e. the AR(1) series is not mean-reverting.

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Properties of $AR(1)$ Process: Unconditional mean

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Properties of an $AR(1)$

Let $t \rightarrow \infty$ in eq. (14):



$$y_t = \alpha_0 \sum_{i=0}^{\infty} (\alpha_1 + \alpha_1^2 + \dots + \alpha_1^i) \varepsilon_{t-i} + \alpha_1^i y_0 \quad (15)$$

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- ▶ The expected value of y_t is given by

$$\begin{aligned} E(y_t) &= E\left((1 + \alpha_1 + \alpha_1^2 + \dots) \alpha_0 + \alpha_1^i y_0 + \sum_{i=0}^{\infty} \alpha_1^i \varepsilon_{t-i}\right) \\ &= E\left((1 + \alpha_1 + \alpha_1^2 + \dots) \alpha_0 + \alpha_1^i y_0\right) \end{aligned}$$

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→ if $|\alpha_1| < 1$: $E(y_t)$ converges to $\frac{\alpha_0}{(1 - \alpha_1)}$

→ if $|\alpha_1| \geq 1$: $E(y_t)$ is time-dependent

Properties of $AR(1)$ Process: Unconditional Variance

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- The variance of y_t is given



$$\begin{aligned} V(y_t) &= E(y_t - E(y_t))^2 \\ &= E\left(\sum_{i=0}^{\infty} \alpha_1^i \varepsilon_{t-i}\right)^2 \\ &= E(\varepsilon_t^2 + \alpha_1^2 \varepsilon_{t-1}^2 + \alpha_1^4 \varepsilon_{t-2}^2 + \dots + \text{cross-products}) \\ &= E(\varepsilon_t^2) + \alpha_1^2 E(\varepsilon_{t-1}^2) + \alpha_1^4 E(\varepsilon_{t-2}^2) + \dots \\ &= (1 + \alpha_1^2 + \alpha_1^4 + \dots) \sigma^2 \end{aligned}$$

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→ if $|\alpha_1| < 1$: $V(y_t)$ converges to $\frac{\sigma^2}{(1 - \alpha_1^2)}$

→ if $|\alpha_1| \geq 1$: $V(y_t)$ is time dependent

Properties of $AR(1)$ Process: ACF

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- The autocovariances γ_k



$$\begin{aligned}\gamma_1 &= \text{cov}(y_t, y_{t-1}) = E((y_t - E(y_t))(y_{t-1} - E(y_{t-1}))) \\&= E((\varepsilon_t + \alpha_1 \varepsilon_{t-1} + \alpha_1^2 \varepsilon_{t-2} + \dots)(\varepsilon_{t-1} + \alpha_1 \varepsilon_{t-2} + \alpha_1^2 \varepsilon_{t-3} + \dots)) \\&= E(\alpha_1 \varepsilon_{t-1}^2 + \alpha_1^3 \varepsilon_{t-2}^2 + \alpha_1^5 \varepsilon_{t-3}^2 + \dots + \text{cross-products}) \\&= \alpha_1 E(\varepsilon_{t-1}^2) + \alpha_1^3 E(\varepsilon_{t-2}^2) + \alpha_1^5 E(\varepsilon_{t-3}^2) + \dots \\&= (\alpha_1 + \alpha_1^3 + \alpha_1^5 + \dots) \sigma^2 \\&= \alpha_1 (1 + \alpha_1^2 + \alpha_1^4 + \dots) \sigma^2\end{aligned}$$

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→ if $|\alpha_1| < 1$: γ_1 converges to $\alpha_1 \frac{\sigma^2}{(1 - \alpha_1^2)}$

→ if $|\alpha_1| \geq 1$: γ_1 is time-dependent

Properties of $AR(1)$ Process: ACF

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$$\begin{aligned}\gamma_2 &= \text{cov}(y_t, y_{t-2}) = E((y_t - E(y_t))(y_{t-2} - E(y_{t-2}))) \\&= E((\varepsilon_t + \alpha_1 \varepsilon_{t-1} + \alpha_1^2 \varepsilon_{t-2} + \alpha_1^3 \varepsilon_{t-3} + \alpha_1^4 \varepsilon_{t-4} + \dots)(\varepsilon_{t-2} + \alpha_1 \varepsilon_{t-3} + \alpha_1^2 \varepsilon_{t-4} + \dots)) \\&= E(\alpha_1^2 \varepsilon_{t-2}^2 + \alpha_1^4 \varepsilon_{t-3}^2 + \alpha_1^6 \varepsilon_{t-4}^2 + \dots + \text{cross-products}) \\&= \alpha_1^2 E(\varepsilon_{t-2}^2) + \alpha_1^4 E(\varepsilon_{t-3}^2) + \alpha_1^6 E(\varepsilon_{t-4}^2) + \dots \\&= (\alpha_1^2 + \alpha_1^4 + \alpha_1^6 + \dots) \sigma^2 \\&= \alpha_1^2 (1 + \alpha_1^2 + \alpha_1^4 + \dots) \sigma^2\end{aligned}$$

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$$\rightarrow \text{if } |\alpha_1| < 1: \gamma_2 \text{ converges to } \alpha_1^2 \frac{\sigma^2}{(1 - \alpha_1^2)}$$

$$\rightarrow \text{if } |\alpha_1| \geq 1: \gamma_2 \text{ is time-dependent}$$

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Properties of $AR(1)$ Process: ACF

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$$\gamma_k = \text{cov}(y_t, y_{t-k}) = E((y_t - E(y_t))(y_{t-k} - E(y_{t-k})))$$

→ if $|\alpha_1| < 1$: γ_k converges to $\alpha_1^k \frac{\sigma^2}{(1 - \alpha_1^2)}$

→ if $|\alpha_1| \geq 1$: γ_k is time dependent

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- The ACF (for stationary series!) is given by

$$\rho_1 = \gamma_1 / \gamma_0 = \alpha_1$$

$$\rho_2 = \gamma_2 / \gamma_0 = \alpha_1^2$$

$$\vdots$$
$$\rho_k = \gamma_k / \gamma_0 = \alpha_1^k$$

AR Process: Stationary Conditions

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Stationarity conditions for AR(1) process

- ▶ $\alpha_1^\infty = 0$
- ▶ $(1 + \alpha_1 + \alpha_1^2 + \dots)$ is finite
- ▶ $(1 + \alpha_1^2 + \alpha_1^4 + \dots)$ is finite
- ▶ $\alpha_1 (1 + \alpha_1^2 + \alpha_1^4 + \dots)$ is finite
- ▶ ...

→ an AR(1) process is stationary if $|\alpha_1| < 1$.

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AR Process: Conclusions

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- ▶ The PACF cuts off after p lags
- ▶ The ACF is infinite in p lags (lies out for covariance stationary processes).
- ▶ The properties of an AR(1) process crucially depend on the value for α_1

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- ▶ If $|\alpha_1| < 1$ the AR(1) process can be written as a stable infinite MA process (the so-called **MA representation**):

$$y_t = \frac{\alpha_0}{1 - \alpha_1} + \sum_{i=0}^{\infty} \alpha_1^i \varepsilon_{t-i}$$

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In this case the series is **stationary** as it has finite constant mean, variance and autocovariances.

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- ▶ If $|\alpha_1| \geq 1$ no stable MA representation exists. In this case the series is **non-stationary** as the mean, variance and autocovariances are time-varying.

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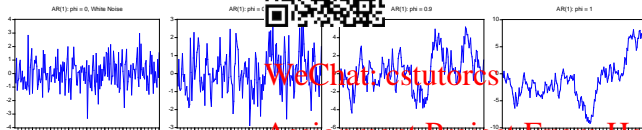
AR(1) Example: Simulated and Fitted

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eg. time series plots

$$\rho_j = \phi_1^j$$

and AR(1)



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eg. NYSE comp return: ϵ_t below is in fact $\mu = \phi_1/(1 - \phi_1)$

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.035159	0.02454	1.43235	0.1523
AR(1)	0.068401	0.022727	3.00976	0.0026

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